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(TITLE UNCLASSIFIED) HYBRID PROPULSION SYSTEM FOR AN ADVANCED ROCKET-POWERED TARGET MISSILE

R. A. Jones

United Technology Center

TECHNICAL REPORT
FEBRUARY 1967

CONTRACT NO. AF 04(611)-11632

Group 4
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Air Force Rocket Propulsion Laboratory
Research And Technology Division
Air Force Systems Command United States Air Force
Edwards, California

UTC 2220-QTR2

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DIVISION OF UNITED AIRCRAFT CORPORATION

17 February 1967
RAS-18-67-F

Air Force Flight Test Center
Edwards Air Force Base
California 93523

Attention: FTMKR-4

Subject: Quarterly Technical Report, UTC 2220-QTR2

Reference: Contract AF 04(611)-11632, DD Form 1423, Item 40

Gentlemen:

United Technology Center herewith effects transmittal of Quarterly Technical Report, UTC 2220-QTR2, in accordance with the referenced contract.

This report covers the period from 1 October through 31 December 1966.

Very truly yours,
UNITED TECHNOLOGY CENTER
A Division of United Aircraft Corporation

R. A. Simmons
Contract Administrator

RAS:vg

This letter downgraded to unclassified if detached from accompanying material.

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(TITLE UNCLASSIFIED) HYBRID PROPULSION SYSTEM FOR AN ADVANCED ROCKET-POWERED TARGET MISSILE

R. A. Jones

UTC 2220-QTR 2

FOREWORD

(U) This is the second quarterly report covering the period from 1 October 1966 to 31 December 1966, and is submitted in compliance with Contract No. AF 04(611)-11632 and in accordance with exhibit B of the Contract Data Requirements List, DD form 1423. The contract was initiated on 1 June 1966 under United Technology Center (UTC) Project 2220, "Hybrid Propulsion System for Advanced Rocket-Powered Target Missile." The work is being administered by the Air Force Rocket Propulsion Laboratory, Edwards Air Force Base, with Mr. F. Mead as the project officer.

(U) This report summarizes the progress made by UTC in the demonstration of the feasibility of using hybrid propulsion systems for advanced rocket-powered target missiles.

(U) Publication of this report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

F. Mead
Project Officer

ABSTRACT

The development of a hybrid propulsion system for an advanced rocket-powered target missile has advanced through the seventh program month. During the past 3 months, the heavyweight motor test series was completed successfully, and designs have been finalized for the flightweight thrust chamber assembly components. The results of the final nozzle evaluation tests have shown that the nozzle configuration selected has a nozzle material erosion rate of 0.45 mils/sec. Motor ignition has been demonstrated at -65° F at sea-level conditions and at a simulated altitude of 50,000 ft. The required thrust ratings have been demonstrated at boost and sustain thrust levels for the durations specified, and step thrust operation has been verified over an 8 to 1 range. The flightweight feed system component buildup has been initiated and cold-flow checkout tests will be conducted during the next reporting period. The current status of the program indicates that the hybrid propulsion units to be used in the flight demonstration prc·;ram will be delivered in accordance with the original schedule.

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ABBREVIATIONS

AFRPL	Air Force Rocket Propulsion Laboratory
c^*	characteristic exhaust velocity
EAFB	Edwards Air Force Base
IRFNA	inhibited red fuming nitric acid
O/F	oxidizer-to-fuel ratio
PG	pyrolytic graphite
TCA	thrust chamber assembly
UTC	United Technology Center

SECTION I

INTRODUCTION

(U) Under Contract AF 04(611)-11632, initiated in June 1966, UTC is conducting a four-phase program to develop a low-cost hybrid propulsion unit and to provide hybrid propulsion systems to be used in a flight demonstration program to prove the feasibility of an advanced hybrid powered target missile. Contained herein is a description of the work conducted during the 3-month period between 1 October 1966 and 31 December 1966.

(U) During the report period, work has progressed in the areas of interface definition, design, analysis, fabrication, and development testing. Interface definition efforts have been confined to an interchange of information with Beech Aircraft Corporation, which has at this time eliminated all foreseeable interface problems. The design and analysis effort has proceeded through the completion of all heavyweight hardware designs and all major flightweight components. Analysis of the test data has been completed for all tests conducted to date. Appendix I of this report contains reduced test data for those firings conducted over the last 3 months. Fabrication of the heavyweight test hardware has been completed with the expection of final incremental hardware deliveries to EAFB which are being used in the parallel development conducted by AFRPL. Flightweight hardware fabrication has been initiated and certain small components have been received.

(U) The heavyweight TCA development testing has been successfully completed. Component designs to be used in the flightweight propulsion system have been developed to the required durability levels by a series of design modifications and evaluation tests. Test data obtained from motor firings conducted with the latest hardware modifications have indicated that the performance requirements will be achieved or exceeded.

(U) At this time, the program schedule continues to reflect the assurance that the propulsion systems deliveries will be accomplished on the required dates. Minor delays that have occurred or that are projected to occur have been primarily the result of a variety of procurement problems; however, the rescheduling of the affected tasks has circumvented possible final delivery delays.

SECTION II

PROGRAM STATUS

1. SCHEDULE

(U) This program is being conducted in four phases: design, development, flight system deliveries, and technical support. The program schedule, figure 1, shows the areas of activity associated with this reporting period.

(U) The schedule shows an extension of the interface definition activity through February 1967. The bulk of the interface definition task was completed during October 1966 as shown; however, it has been found that minor detail changes continue to develop as UTC and Beech continue into the hardware fabrication areas. The schedule extension, therefore, reflects the low level of effort that is required to add these minor changes to the interface control drawing.

(U) The scheduled activity for design and analysis remains unchanged as this effort continues.

(U) A number of activities have been rescheduled in phase II, primarily because of flightweight feed system hardware procurement delays. The projected feed system test delays allowed a stretchout of the heavyweight TCA tests, which can be shown to be of benefit to the overall program. The TCA test stretchout provided time for at least one more design improvement change and motor firing evaluation. In addition, more test results became available from the parallel development program being conducted by AFRPL and which were integrated into the overall design plans.

(U) Phase III, Flight System Deliveries remains as originally scheduled. The delays in the phase II activity completion dates will not affect the initial fabrication activities go-ahead.

(U) Applicable program mileposts of figure 2 have been changed to reflect the rescheduling of program activities.

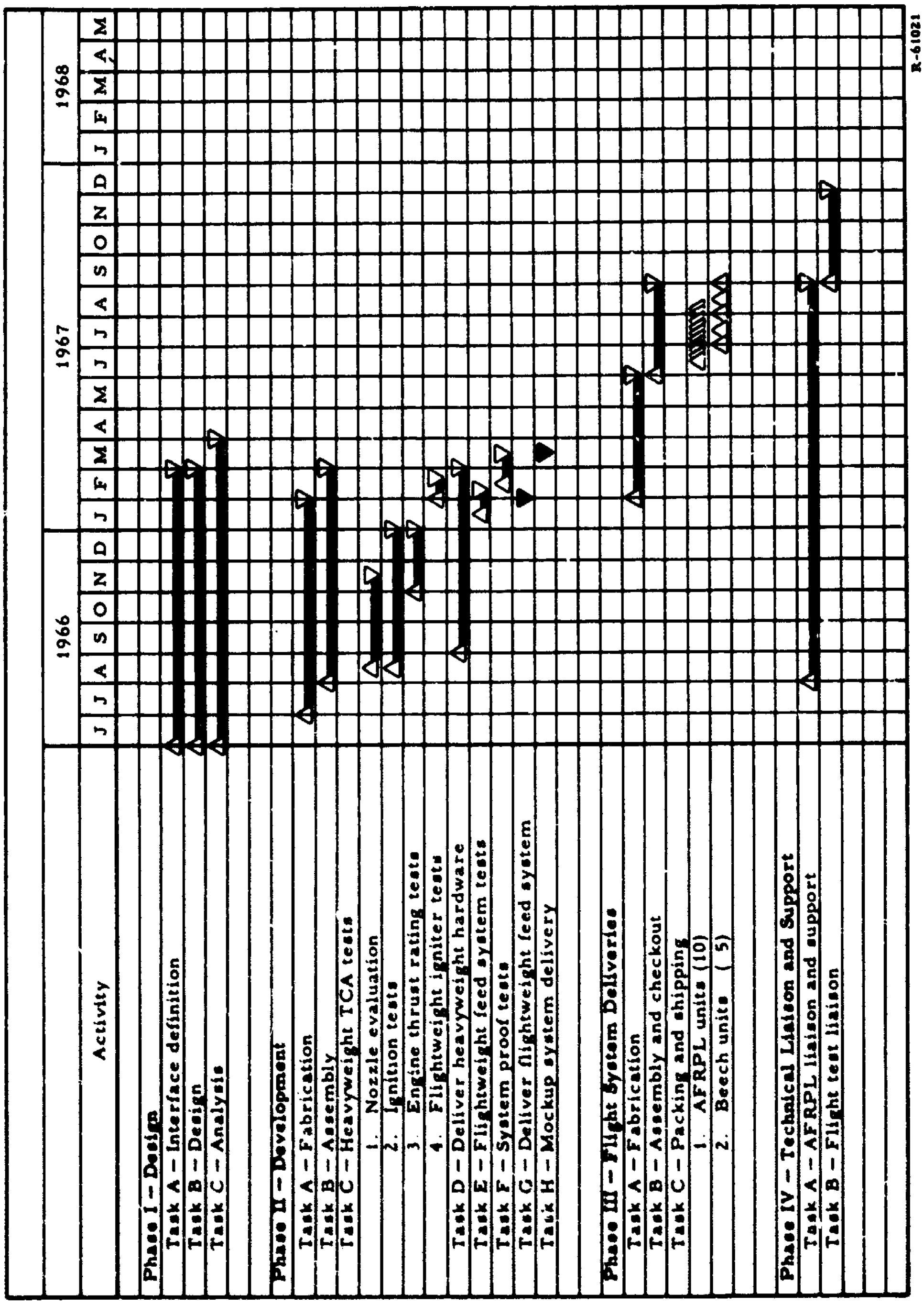

Figure 1. (U) Hybrid Propulsion System Program Schedule

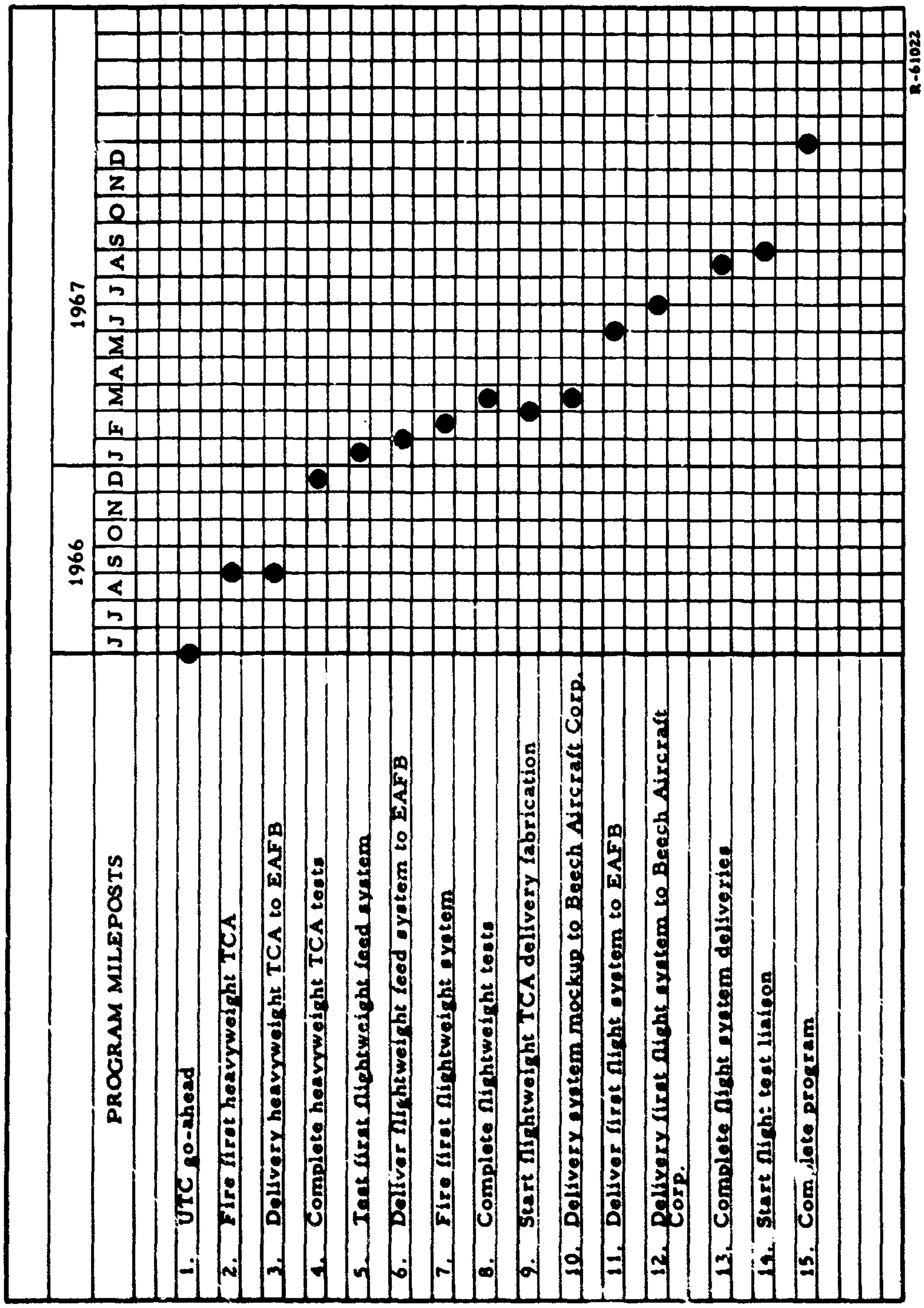

Figure 2. (U) Hybrid Propulsion System Milepost Schedule

2. WORK ACCOMPLISHED

a. Mileposts

(U) During this reporting period, milepost No. 4, Complete Heavyweight TCA Test, was completed. The information gained during this test series will assure that the flightweight hardware to be tested during the system proof tests will satisfy the performance requirements.

b. Interface Definition

(U) Plumbing and fitting details of the flightweight feed system were modified to comply with a Beech Aircraft Corporation revision request. In addition, a minor change to the flightweight thrust chamber design in the vicinity of the chamber aft closure was made to eliminate a possible interference problem. All major revisions were made to the UTC/Beech interface control drawing and it is considered baseline at this time. Minor detail changes are expected throughout the flightweight hardware buildup period; however, these revisions will not affect the UTC or Beech Aircraft Corporation delivery schedule.

c. Design and Analysis

(U) The design and analysis of the heavyweight hardware was completed and several major nozzle design revisions were completed as a result of the hardware eveluation tests. The heavyweight hardware design activity is considered complete.

(U) During this reporting period, the majority of the flightweight hardware components were designed and analyses initiated. The flightweight thrust chamber was designed and a stress analysis was completed and is presented as appendix II. The design was found to be structurally adequate and the weight estimates predict the hardware will fall within the original weight allowance.

(U) The design of the prototype feed system which involves all plumbing and fitting details was completed. Designs have been completed or off-the-shelf hardware selected for other major feed system components such as control valves, regulators, relief valves, fill valves, burst diaphragms, and the dial-a-thrust flow control valve. The final hardware drawings of the flightweight igniter assembly have been completed and a complete procurement package has been prepared.

(U) Based on the results of the heavyweight TCA motor firings, minor modifications to the flightweight TCA components were made. An assembly drawing of the TCA was prepared and detailed stress and thermal analyses have been initiated.

(U) Test plans are being prepared for the structural and vibration proof tests and the design of the test fixtures has been initiated.

(U) Detailed drawings of the flightweight hardware shipping containers have been completed and formal Interstate Commerce Commission safety classification approval is expected.

d. Heavyweight Hardware Fabrication and Assembly

During this reporting period, the following quantities of heavyweight TCA components were fabricated and assembled for motor firings:

12 - Nozzle Assemblies
10 - Fuel Grain Assemblies
16 - Igniter Assemblies
3 - Injector Assemblies

(U) In addition, five nozzle assemblies and five fuel grain assemblies were fabricated and assembled to make up the second incremental delivery of these components to EAFB.

(U) In conjunction with the fabrication of the heavyweight TCA components, various tooling hardware and assembly fixtures were procured or modified to facilitate design changes.

e. Flightweight Hardware Fabrication and Assembly

(U) The fuel grains to be used for the proof test firings were fabricated and are undergoing final inspection.

(U) The flightweight tankage is being fabricated and initial deliveries are expected during the first week of the next reporting period. The remaining feed system components were received with the exception of miscellaneous fittings which are expected momentarily.

(U) The flightweight thrust chamber procurement has been initiated and the vendor has initated procurement of long lead-time materials and tooling. Fabrication of chamber components was started the last week of this reporting period and final assembly is scheduled for the first week in February 1967.

(U) The first flightweight flow control valve was fabricated and assembled for initial heavyweight TCA duty cycle tests.

(U) Procurement of the prototype igniter initiator has been started and a fabrication go-ahead will be given during the first month of the next reporting period.

f. Heavyweight TCA Tests

(U) During this reporting period 13 motor firings were conducted, 4 igniter assemblies were fired during open-air tests, and a number of facility cold flow calibrations were run. A summary of these development tests, Nos. 21 through 39, is shown in table I. Detailed test results of motors fired during this reporting period are presented by test number in appendix I.

g. Deliveries and Documentation Transmittals

(U) One nozzle assembly, taken from the second incremental delivery buildup of these components, was delivered to AFRPL.

(U) A set of heavyweight component drawings were transmitted informally to AFRPL. In addition, a revised copy of the UTC coordination drawing has been transmitted to Beech Aircraft Corporation to provide revision details for the Beech/UTC interface control drawings.

h. Technical Liaison and Support

(U) During the second week of November 1966, UTC personnel went to EAFB to provide heavyweight hardware assembly instructions. During the last week of November, UTC personnel in the company of Eglin AFB and Beech Aircraft Corporation personnel, witnessed the first altitude firing of a heavyweight TCA at EAFB. A program review involving informal status presentation by those in attendance was also held at this time.

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TABLE I

(U) HEAVYWEIGHT TCA DEVELOPMENT TESTS SUMMARY

Test No.	Date	Objective	Primary Result	Comment
H3S-21	4 October	Fire heavyweight TCA and evaluate fuel grain insulation material at sustain thrust level.	Performance of the silicon insulation was consistent with results of previous firings.	Test was successful; the 1.0 expansion ratio nozzle withstood 134-sec duration with no erosion.
H3S-22	6 October	Fire heavyweight TCA and evaluate nozzle material at boost thrust level.	The Speer SX4 graphite nozzle coated with silica carbide experienced 4.5 mils/sec erosion during the 95-sec firing. The silica carbide coating was completely removed in the throat regions.	Test was successful.
H3S-23	10 October	Check out facility conditioning box at -65° F.	The conditioning box interior was reduced to -65° F within a brief time period and automatic temperature controls functioned properly.	Detailed test results are available in oscillograph form.
H3S-24	13 October	Fire heavyweight TCA following conditioning at -65° F and evaluate motor ignition.	The TCA was conditioned for 10 hr to achieve an equilibrium temperature of -65° F. Motor ignition occurred within 300 msec.	Test was successful.
H3S-25	14 October	Fire heavyweight TCA and evaluate nozzle material at boost thrust level.	The Speer graphite nozzle coated with zirconium oxide experienced 3.9 mils/sec erosion during the 95-sec firing. The zirconium oxide coating was completely removed in the throat region.	Test was successful.
H3S-26	19 October	Evaluate heavyweight TCA igniter in open-air firing at -65° F.	A modified initiator was used to ignite the igniter propellant charge at -65° F. The initiator provided rapid ignition with moderate overpressure.	Test was successful. Detailed test results available in oscillograph form.
H3S-27	20 October	Fire heavyweight TCA and evaluate motor performance at sustain thrust level using modified injector.	Performance of the motor was satisfactory. The required chamber pressure was achieved and the effects of the modified injector were observed.	Test was successful; the 1.0 expansion ratio nozzle withstood the 155-sec duration with 0.2 mils/sec erosion. The flow control valve was used to maintain oxidizer flow rate setting.
H3S-28	20 October	Evaluate heavyweight TCA igniter in open-air firing at -65° F.	Ignitiator reproducibility was verified at -65° F.	Test was successful; this test was a repeat of test No. H3S-26.
H3S-29 H3S-30	21 October 24 October	Evaluate heavyweight TCA igniter in open-air firing at +165° F.	A modified initiator was used to ignite the propellant charges at +165° F. The initiator provided rapid ignition with moderate overpressure.	Tests were successful; these tests involved the same initiator and igniter hardware design used in tests H3S-26 and H3S-28.
H3S-31	25 October	Fire heavyweight TCA	The pyrolytic graphite nozzle insert	Test was successful

		... level using modified injector.	... and the effects of the modified injector were observed.	... withstood the 155-sec duration with 0.2 mils/sec erosion. The flow control valve was used to maintain oxidizer flow rate setting.
H3S-28	20 October	Evaluate heavyweight TCA igniter in open-air firing at -65° F.	Ignitiator reproducibility was verified at -65° F.	Test was successful; this test was a repeat of test No. H3S-26.
H3S-29 H3S-30	21 October 24 October	Evaluate heavyweight TCA igniter in open-air firing at +165° F.	A modified initiator was used to ignite the propellant charges at +165° F. The initiator provided rapid ignition with moderate overpressure.	Tests were successful; these tests involved the same initiator and igniter hardware design used in tests H3S-26 and H3S-28.
H3S-31	25 October	Fire heavyweight TCA and evaluate nozzle material at boost thrust level.	The pyrolytic graphite nozzle insert experienced 0.96 mils/sec erosion during the 95-sec firing.	Test was successful.
H3S-32	17 November	Fire heavyweight TCA and evaluate mixer redesign during duty cycle at boost and sustain thrust levels.	The pyrolytic graphite nozzle insert experienced 4.8 mils/sec erosion during the 93-sec boost portion. The firing continued an additional 180 sec at sustain for a total duration of 273 sec.	Test was successful; the flow control valve was used to maintain oxidizer flow rate setting.
H3S-33	22 November	Fire heavyweight TCA and evaluate mixer redesign during duty cycle at boost and sustain thrust levels.	The pyrolytic graphite nozzle insert experienced 0.3 mils/sec erosion during the 93-sec boost operation. The firing continued an additional 147 sec at sustain for a total of 240 sec.	Test was successful; however, an unexpected hot spot required premature shut down. The flow control valve was used to maintain oxidizer flow rate setting.
H3S-34	29 November	Fire heavyweight TCA and verify performance of alternate oxidizer.	Motor ignition was accomplished and stable operation at boost and sustain thrust levels was demonstrated using the alternate oxidizer (IRFNA).	Test was successful.
H3S-35	8 December	Fire heavyweight TCA and evaluate duty cycle performance.	Following a 93-sec boost phase, the firing continued an additional 36 sec at sustain for a total of 129 sec.	Test was partially successful; an unexpected hot spot required premature shut down. The flow control valve was used to maintain oxidizer flow rate setting.
H3S-36	15 December	Cold flow facility feed system to obtain new calibration curve following system modifications.	Facility pressure drop characteristics as a function of oxidizer flow rate were determined.	Detailed test results are available in oscillograph form.
H3S-37	16 December	Fire heavyweight TCA and evaluate duty cycle performance.	The pyrolytic graphite nozzle insert experienced 0.285 mil/sec erosion during the 93-sec boost operation. The firing continued an additional 180 sec at sustain for a total of 273 sec.	Test was successful; the flow control valve was used to maintain oxidizer flow rate setting.
H3S-38	19 December	Fire heavyweight TCA and evaluate duty cycle performance.	The pyrolytic graphite nozzle insert experienced 0.6 mils/sec erosion during the 95-sec boost operation. The firing continued an additional 300 sec at sustain for a total of 395 sec.	Test was successful; the flow control valve was used to maintain oxidizer flow rate setting.
H3S-39	30 December	Fire heavyweight TCA following conditioning at -65° F and evaluate motor ignition at a simulated altitude of 50,000 ft.	The TCA was conditioned for 12 hr to achieve an equilibrium temperature of -65° F. Motor ignition occurred within 600 msec at a minimum pressure altitude of 50,000 ft.	Test was successful.

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SECTION III

TEST RESULTS DISCUSSION

1. NOZZLE MATERIAL EVALUATION

(U) The nozzle material evaluation was completed and a pyrolytic graphite throat insert has been selected for the flightweight design. A summary of the test results which led to this conclusion is presented in table II.

(U) As discussed in a previous report, it was decided to evaluate an oxidizer-resistant nozzle coating which would protect the graphite substrate in much the same manner as the magnesium oxide buildup had protected the nozzle in previous tests. Both silicon carbide and zirconia oxide were selected for evaluation. A 0.010-in. uniform coating of silicon carbide was applied over the nozzle entrance, throat, and exit cone of a graphite substrate which was selected on the basis of similar thermal expansion characteristics. Test No. H3S-22 was then conducted at boost condition for 95 sec and, as shown in table II, throat erosion averaged 4.5 mils/sec. The silicon carbide coating appeared to have little effect in reducing erosion in the throat region even though the coating remained intact on the nozzle entrance and exit cone surfaces. The zirconia oxide coating was evaluated by applying a 0.10-in. uniform coating on a Speer Carbon graphite nozzle made of the same material previously tested uncoated (H3S-19). Test H3S-25 was then conducted at boost conditions for 95 sec and, as shown in table II, throat erosion averaged 3.9 mils/sec. Again the coating did not reduce the throat erosion. The value of 3.9 compares with the 4.0 value during test H3S-19 for the uncoated material. Further effort with the coating approach could not be justified because of the nozzle cost increases associated with thicker coatings and proprietary coating techniques. Successful coating techniques require extensive structural support of the substrate material to minimize thermal stress, and such requirements could be expected to increase cost and weight. Of the original candidates, only pyrolytic graphite remained to be evaluated, which could now be justified based on the lack of success with inexpensive coatings.

(U) Test No. H3S-31 was then conducted with a pyrolytic graphite (PG) throat insert at boost conditions for 95 sec. As shown in table II, throat erosion averaged 0.96 mils/sec, which was regarded as a new low. The success of this test posed the question of whether or not PG would attract slag similar to the Speer graphite candidate when used in conjunction with

TABLE II

(U) NOZZLE MATERIAL EVALUATION TEST SUMMARY

Test No.	Chamber Pressure psia	Chamber Pressure psia	Duration sec	Nozzle Erosion mils/sec	Material
H3S-22	490	150	95	4.5	Speer Grade SX4 graphite coated with silicon carbide
H3S-25	480	180	95	3.9	Speer Grade 9139 graphite coated with zirconium oxide
H3S-31	500	470	95	0.96	Pyrolytic graphite insert with ATJ graphite backup
H3S-32	500	170	95	4.8	Pyrolytic graphite insert with ATJ graphite backup (chamber mixer used)
H3S-33	480	515	93	0.3	Pyrolytic graphite insert with ATJ graphite backup (ramped entrance section)

a mixer. Previous in-house tests conducted with PG throat inserts at boost conditions for durations up to 50 sec indicated no slag buildup with a mixer. The mixer design was therefore modified as shown in figure 3 to incorporate a larger plenum and gradual contours to minimize the flow tripping action previously seen to encourage slag buildup. Test No. H3S-32 was then conducted to boost conditions for 95 sec and, as shown in table II, throat erosion averaged 4.8 mils/sec. The slag buildup did not occur; however, the mixer increased the nozzle erosion rate by a factor of five. The decision was then made to eliminate the mixer on all future tests based on a tradeoff between an expected mixer contribution of 2% improved combustion efficiency and an average thrust coefficient improvement of 10% for a nozzle without a mixer. The thrust coefficient improvement was contributed to by the higher average chamber pressure and nozzle expansion ratio, both of which are obtained with minimum throat erosion. It was also apparent at this juncture that further reduction in nozzle erosion may be obtained by using a very gradual nozzle approach angle with a full radius entrance. Figure 4 shows the modified entrance geometry which produced nozzle erosion as low as 0.3 mils/sec as shown in table II for Test No. H3S-33. The average erosion rate for all the tests conducted to date using this nozzle design has been 0.45 mils/sec.

(U) The selection of the present nozzle configuration for the flightweight design has also been based on the results of the thermal analysis. Continuous boost-sustain firings such as H3S-38, which exceeded a duration of 6.5 min, have provided thermocouple data as shown in figure 5. The results show a maximum skin temperature of 410° F at the end of the firing and a final thermal soak temperature of 600° F after 14 minutes. The analytical results obtained with the thermal model as shown in figure 6 predict maximum skin temperatures of 450° F at the end of the firing, which is slightly conservative. A projection of the thermal model based on these correlations has been used to predict the skin temperature of the flightweight nozzle hardware. These results, shown in figure 7, indicate that a maximum temperature of 1,000° F can be expected at the end of the firing. The stresses developed in the 18-nickel maraging steel by the sustain pressure loads are only 10% of the ultimate strength for this material at 1,000° F, indicating the high margin of safety available with this nozzle configuration.

2. PERFORMANCE

(U) Performance evaluation of the hybrid motor has been accomplished by the "Hybrid Motor Performance Analyzer" computer program presented in appendix III. This program is basically a data reduction program which utilizes the test results as input. The program calculates instantaneous throat area, specific impulse, O/F ratio, fuel flow rate, c^*, c^* efficiency,

fuel grain port radius, expansion ratio, total oxidizer weight consumed, regression rate, and oxidizer flow rate per unit port area. In addition, options exist which allow the reduced test data to be corrected for altitude operating conditions.

(U) A comparison of recent motor firings at boost conditions has been made, as shown in figure 8. This figure shows the 95-sec boost requirement for the 90,000-ft altitude cruise mission compared with test No. H3S-38. This corrected sea-level data meets or exceeds the boost thrust requirements and represents a typical boost thrust-time curve that can be expected during the flightweight hardware tests.

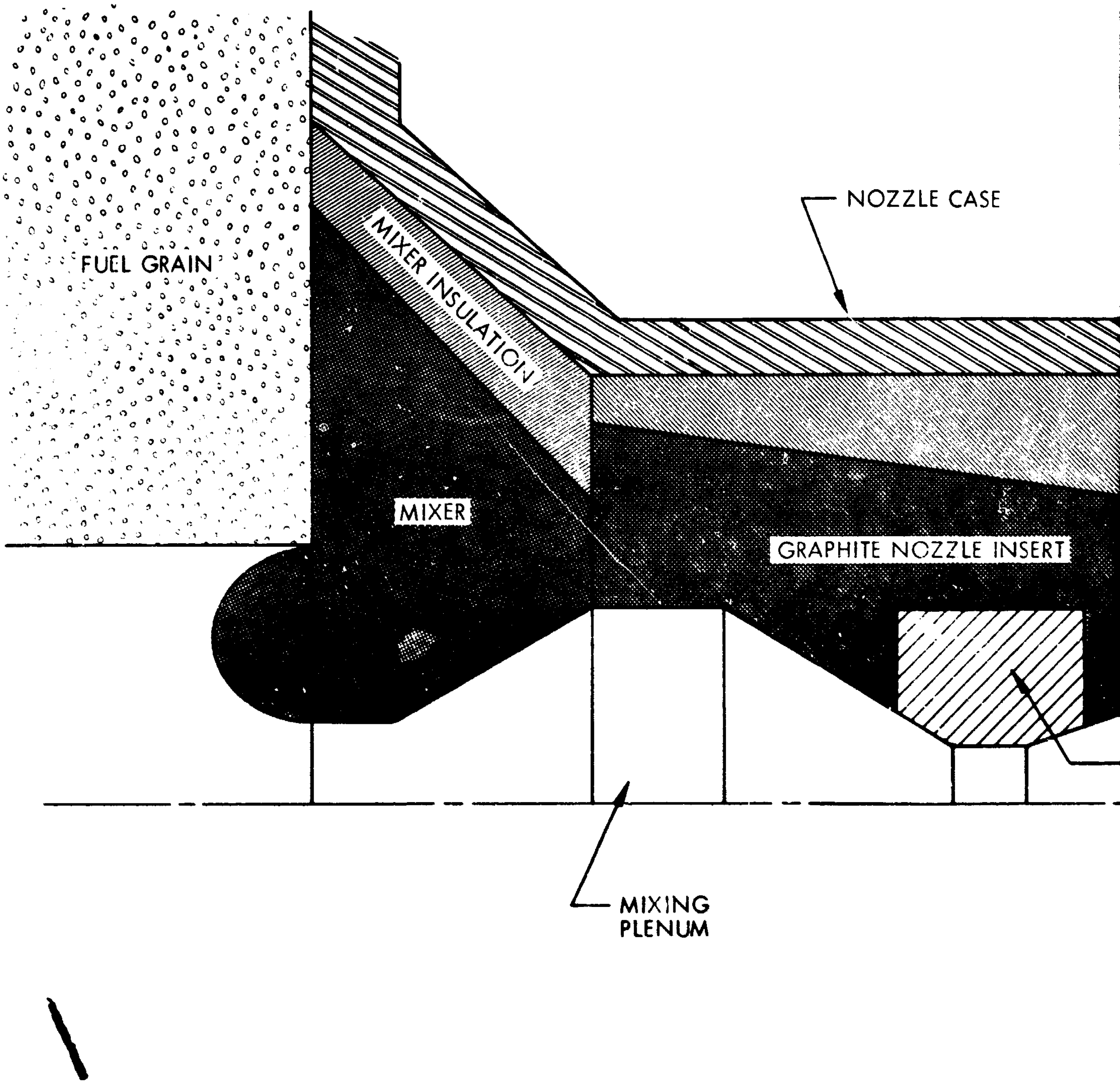
(U) Sustain thrust performance at altitude conditions, as shown in figure 9, was obtained by correcting the thrust data obtained during sustain firings conducted with a 1.0 expansion ratio nozzle and from the duty cycle tests, by calculating the thrust from chamber pressure measurements. It should be noted that the sustain thrust data shown for the duty cycle tests in appendix I have been measured while the nozzle is flowing in a separated condition. Figure 9 shows the relationship between sustain thrust and the oxidizer flow rate over the range of primary interest. The flow control valve setting may be obtained from the curve for the 80,000-ft cruise requirement, and further data corrections will provide settings for the other cruise altitude requirements. A nozzle expansion ratio of 21 has been referenced on figure 9 to account for the nozzle expansion ratio reduction resulting from throat erosion during boost. At the beginning of a duty cycle, the nozzle expansion ratio is 25 and, depending on the duration of boost, the ratio can be expected to reduce slightly; however, this change is reproducible and does not affect the accuracy of the predetermined sustain thrust settings. Figure 10 shows the variation of nozzle expansion ratio as a function of boost thrust duration as obtained from recent firings using the final nozzle configuration.

(U) The heavyweight motor firing test data have demonstrated that the required boost thrust levels and sustain thrust durations will be achieved and that flightweight hardware designs based on the final heavyweight motor configuration will satisfy all performance requirements.

3. IGNITER PERFORMANCE

(U) The pyrogen igniter development has been completed and the test results proved that the design is capable of igniting the motor over a temperature range of -65° to +165° F.

(U) The pyrogen igniter selected has been tested over the required temperature range and produces igniter chamber pressures as shown in figure 11. The pressure-time curves show that the initiator provides ignition



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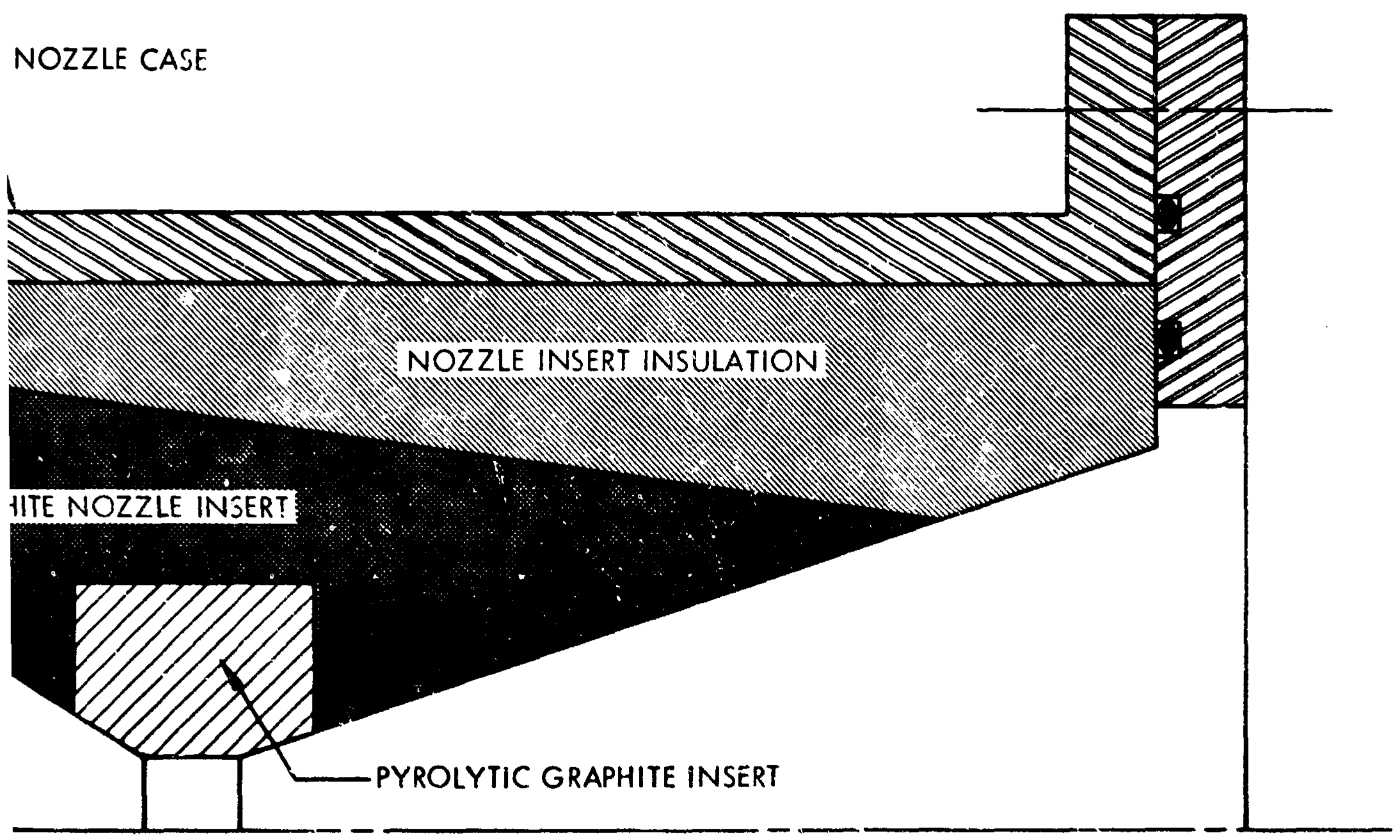

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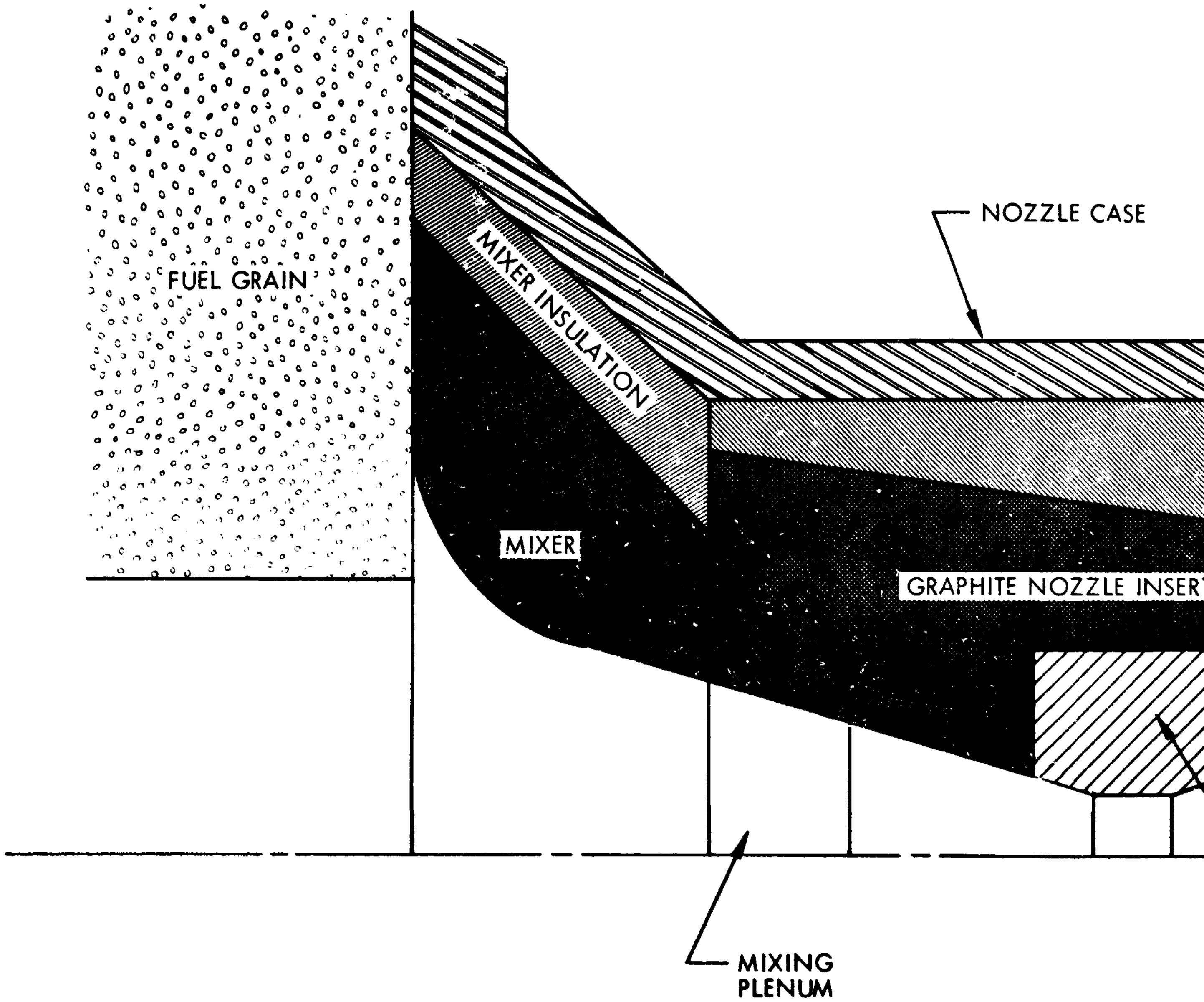
Figure 3. (U) Modified Heavyweight Nozzle Configuration



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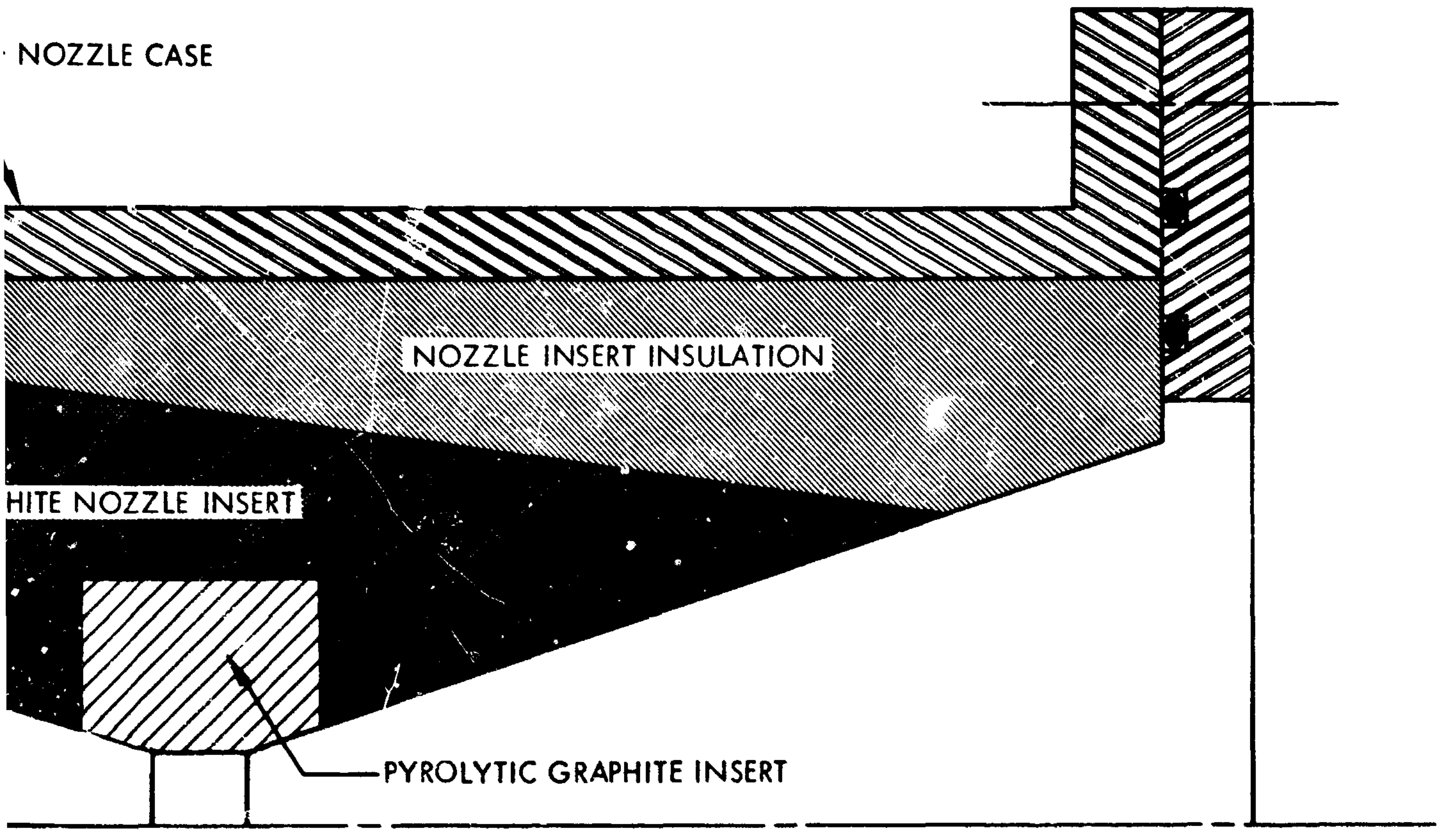

Figure 4. (U) Modified Entrance of Modified Heavyweight Nozzle Configuration

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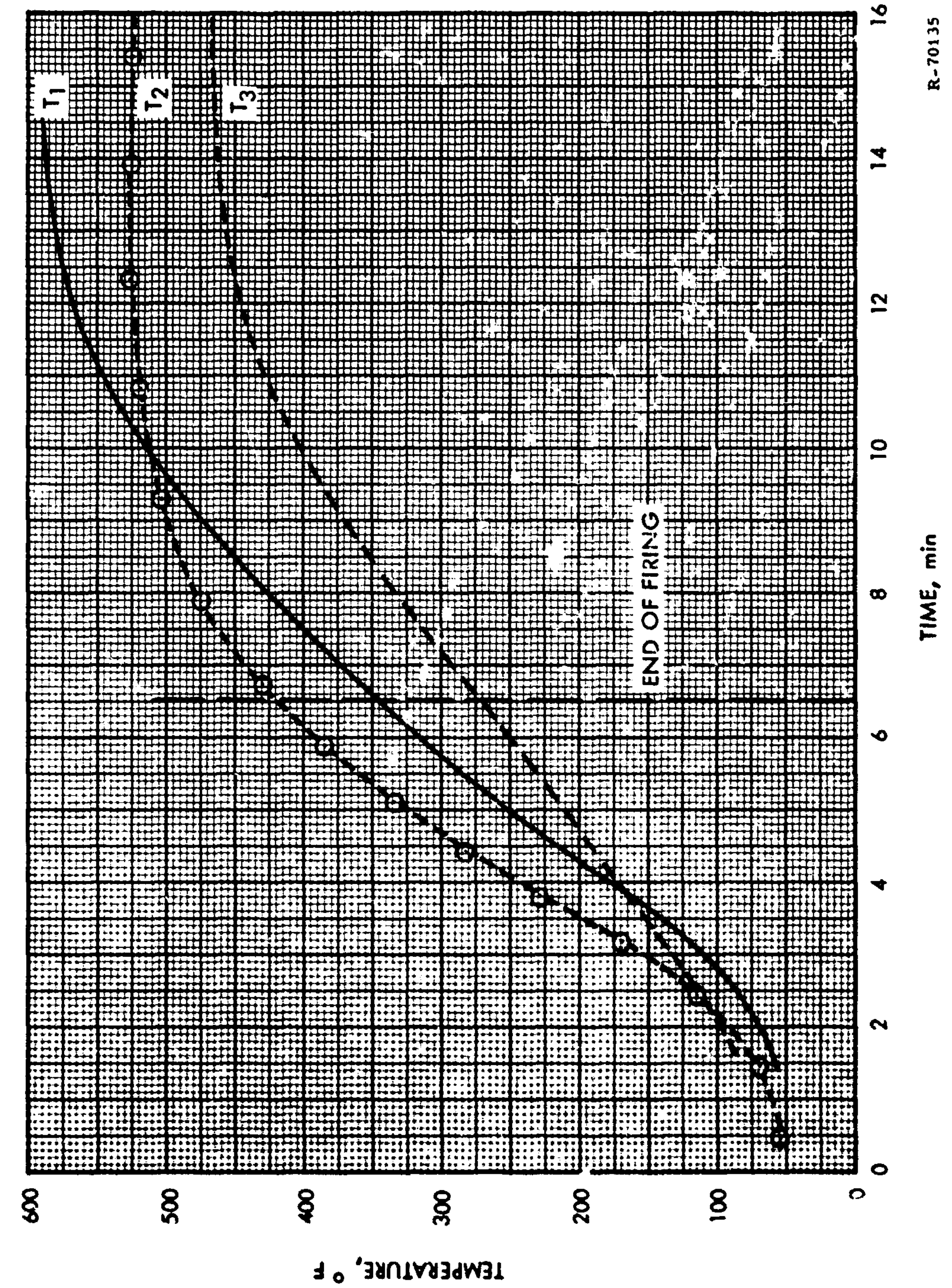


Figure 5. (U) Thermocouple Response of Test No. H3S-38

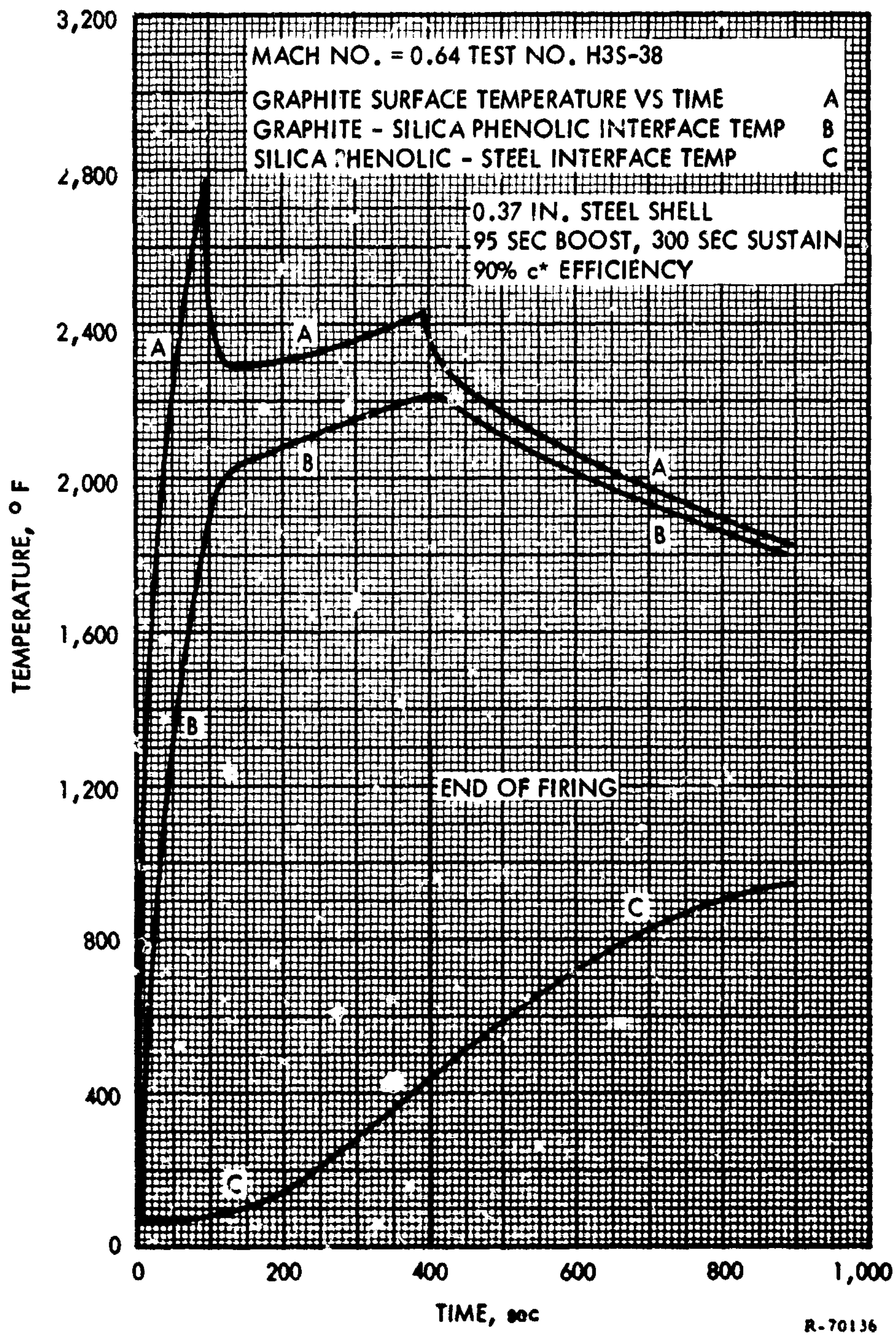


Figure 6. (U) Hybrid Target Missile Thermal Analysis, 0.37-in. Steel Shell

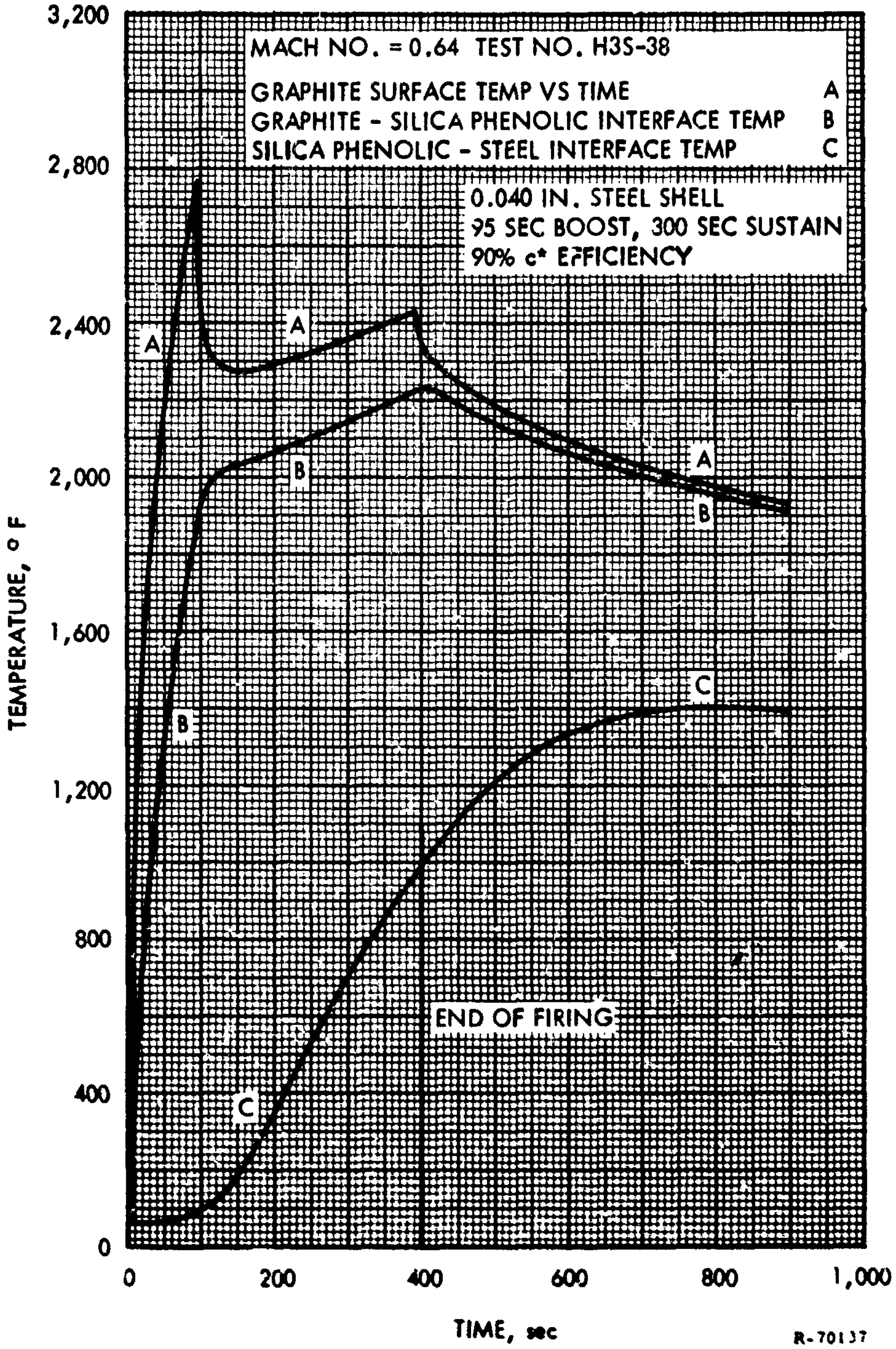


Figure 7. (U) Hybrid Target Missile Thermal Analysis, 0.040-in. Steel Shell

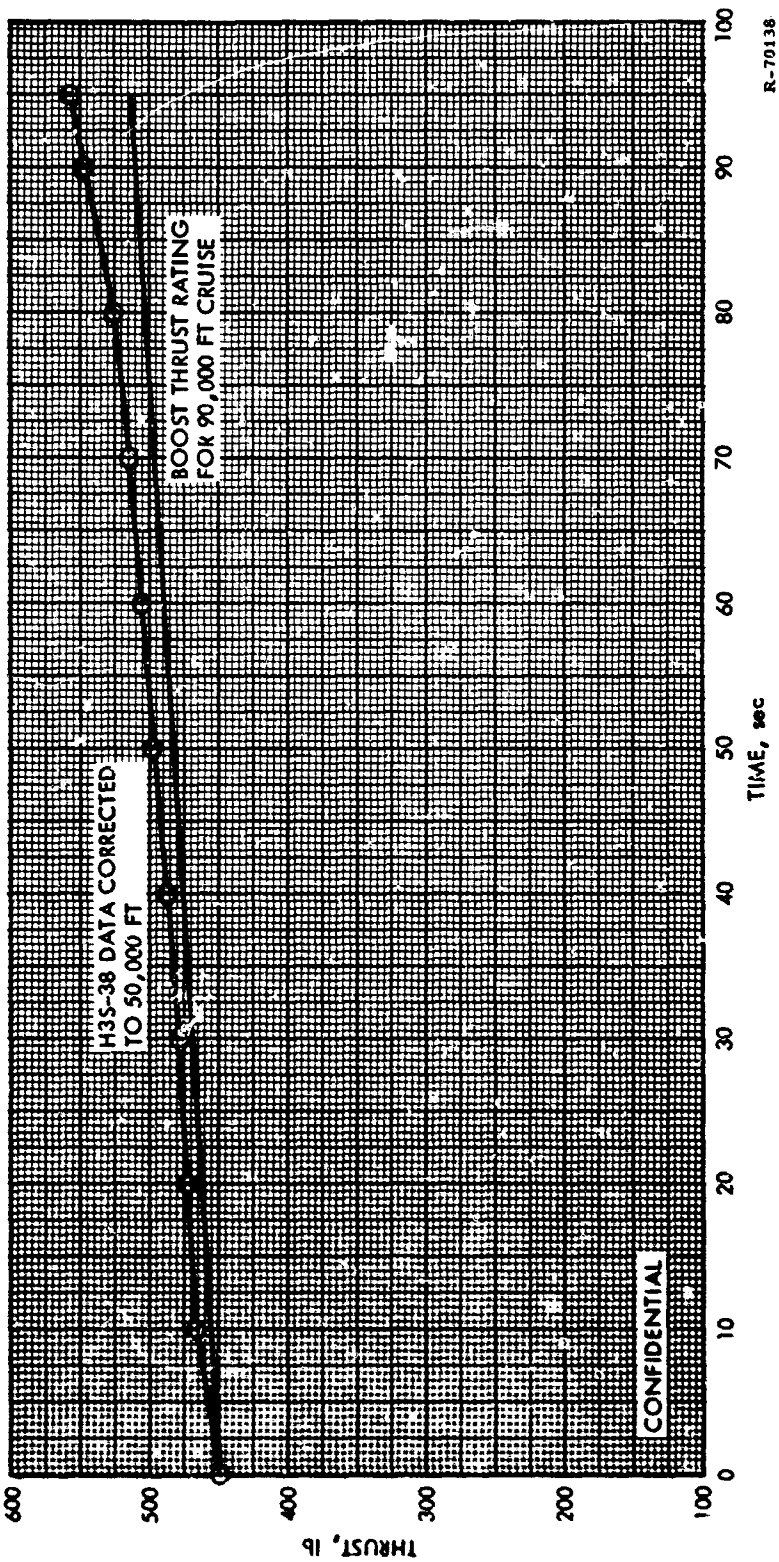


Figure 8. (U) Comparison of the 90,000-ft Altitude Cruise Boost Thrust Requirements and Data from Test No. H3S-38

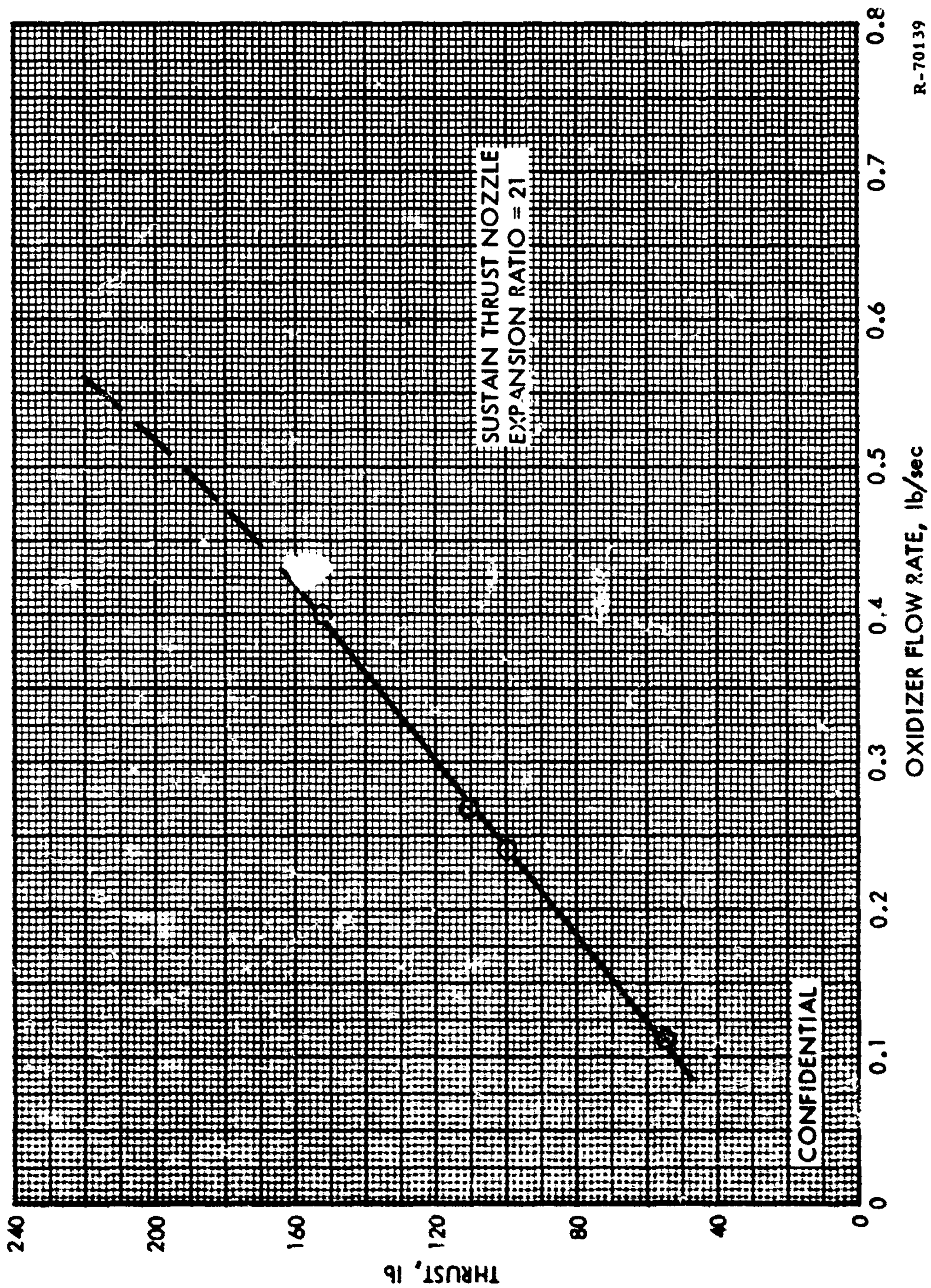


Figure 9. (U) Sea-Level Sustain Performance Corrected to 80,000-ft Altitude

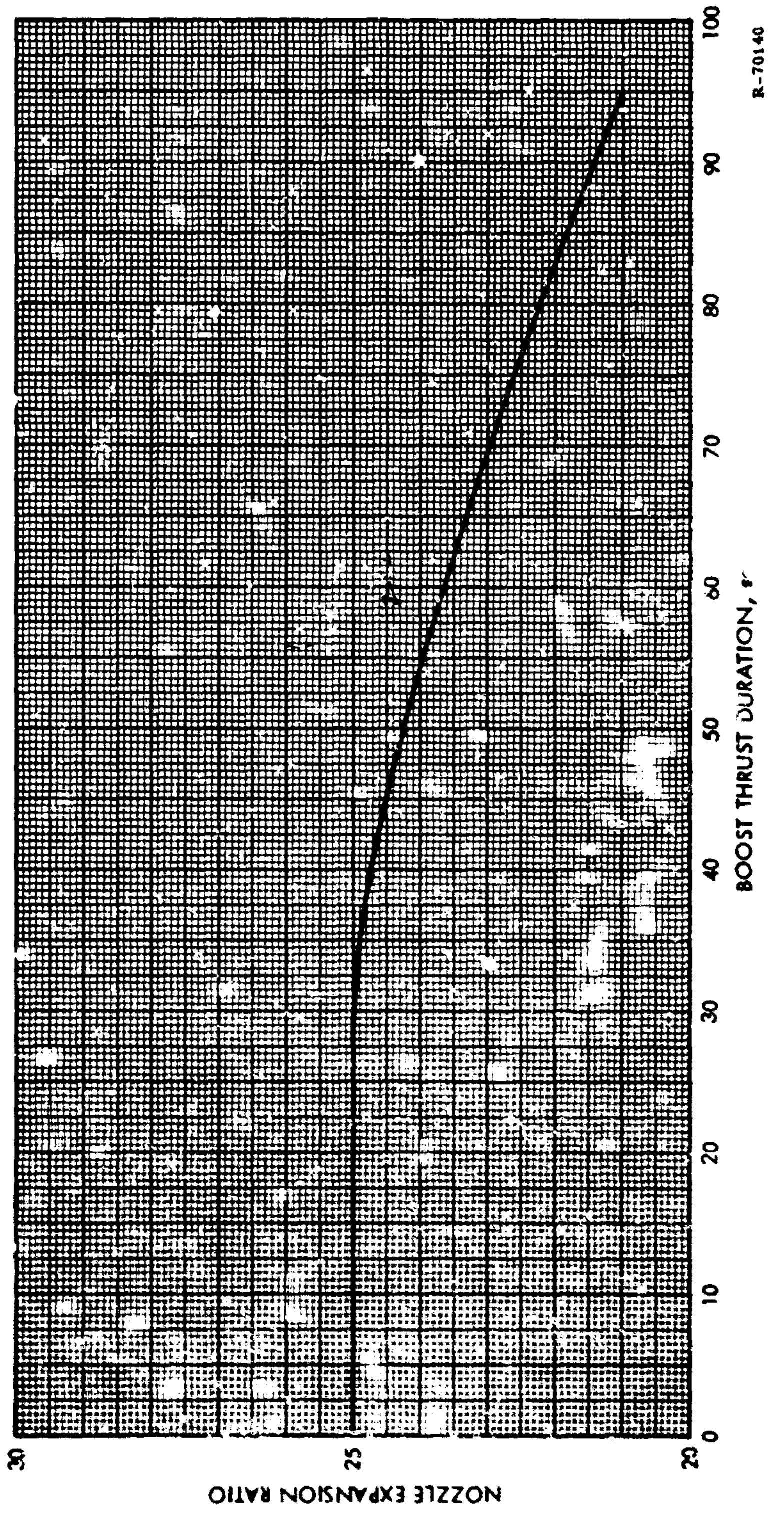
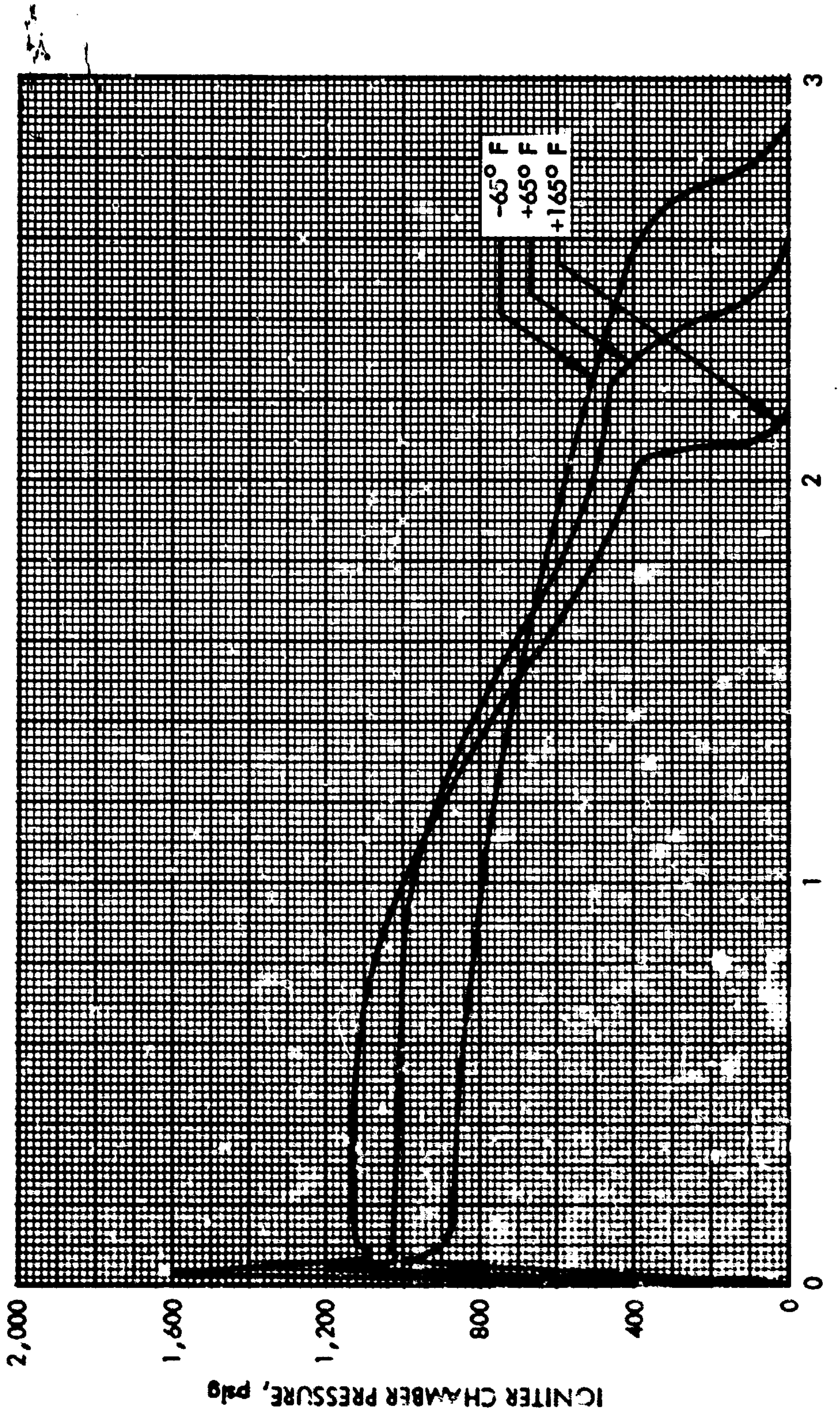


Figure 10. (U) Nozzle Expansion Ratio Variation as a Function of Boost Time Caused by Nozzle Throat Erosion



R-70141

Figure 11. (U) Igniter Open-Air Performance at Various Conditioning Temperatures

at -65° F without excessive overpressurization at +165° F. A minimum 2-sec action time is provided over the temperature range which provides the required sequencer flexibility during motor ignition.

(U) The performance of the pyrogen igniter in conjunction with the motor has been tested at ambient conditions, (all motors fired to date have used this igniter design), at -65° F, and at -65° F with 50,000-ft simulated altitude conditions. Motor ignition at +165° F has not been considered a development problem and therefore will be evaluated during the flightweight proof test phase. Motor ignition at -65° F was demonstrated during test No. H3S-24 as shown in figure 12. The start sequence provided an igniter leadtime of approximately 1.0 sec followed by the oxidizer valve start signal. The facility oxidizer valve delay and liquid transport time results in a flow rate buildup duration of 100 msec, with full motor chamber pressure developed within 300 msec following the oxidizer start signal. A portion of the facility-supplied oxidizer was conditioned to -65° F during this test to assure that the oxidizer used during the start transient would represent the operation of a complete flight feed system soaked at -65° F. Following the successful ignition at -65° F, an ignition test was then conducted at -65° F in conjunction with a simulated altitude environment of 50,000 ft. The 50,000-ft launch altitude was simulated by an altitude start tank which was able to maintain a near vacuum pressure during the ignition transient. The results of this test are shown in figure 13. The start sequence provided an igniter leadtime of approximately 0.25 sec prior to the oxidizer valve start signal. The facility oxidizer valve delay and liquid transport time required a flow rate buildup duration of 300 msec. Following the arrival of the oxidizer, motor ignition required a delay of 600 msec before achieving full chamber pressure. The effect of a 50,000-ft environment can be seen to delay ignition; however, the igniter performance is well within the acceptable delay limits while being subjected to this combination of -65° F environment and 50,000-ft simulated altitude.

4. FUEL GRAIN INSULATION EVALUATION

(U) During the heavyweight duty cycle tests it was necessary to prematurely terminate some of the tests because of excessive heat on the forward portion of the motor. Slight variations in the test conditions made it difficult to analyze the problem initially; however, based on postfire examinations, it appeared that excessive circulation had suddenly developed at the head end, which attacked the fuel and the forward closure insulation. Hot spots appeared on the forward closure and on the motor case during the tests much earlier than intentional insulation burn throughs had occurred on previous tests and earlier than had been predicted for these tests. This seemed to indicate the possibility that some seemingly minor design change had developed this problem. A careful review of injector design changes

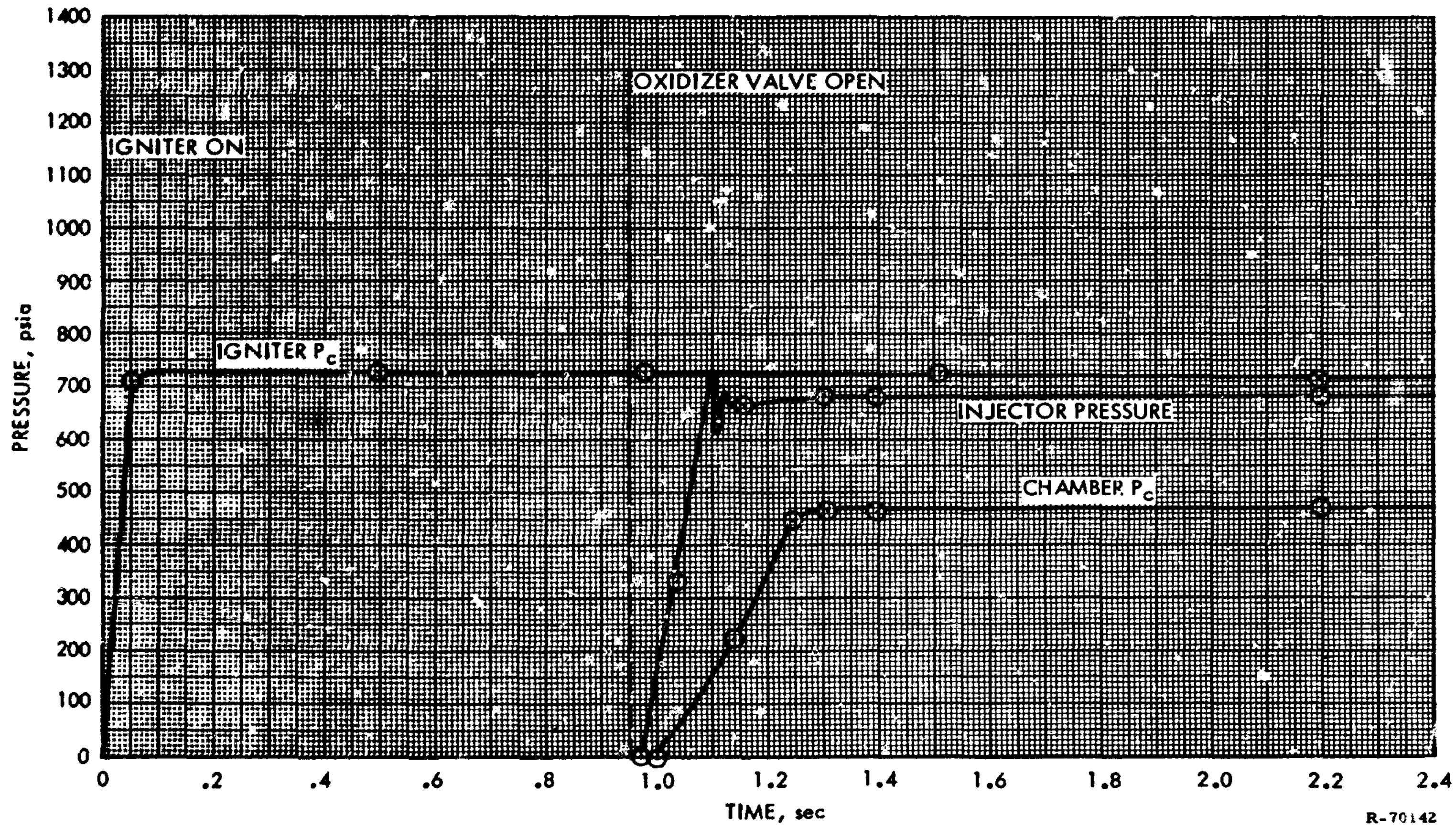


Figure 12. (U) P_{ci}, P_c, P_{io} vs Time, Test No. H3S-24, -65° F

could not explain this condition until a small piece of deposit built up by the combustion gases, bearing an impression of the injector face, was discovered in the chamber after the test. It could then be seen that some of the injector designs which incorporated a larger exposed surface to the combustion gases might build up deposits which would cling momentarily before being dislodged by the circulation. Before being dislodged, the deposit would deflect the oxidizer to the side, causing excessive fuel utilization and premature insulation burn through. The injector designs having the larger exposed surface areas were of the same internal design as the earlier injectors, the only difference being a method of fabrication change which resulted in a lower projected production unit cost. The low-cost design has now been modified to achieve a minimum amount of exposed surface area by removing more material during the machining operation.

(U) The resolution of this problem did not result in a fuel grain insulation change; however, an additional precaution has been taken on the design of the forward closure insulation. The flightweight hardware forward closure insulation has been thickened by 33% to assure adequate protection for the exposed injector face under the worst conditions of insulation ablation. The thickened insulation provides a recess for the injector early in the firing, thereby diverting the circulating chamber gases away from the injector face. The failures normally occurred during the boost phase or shortly after the beginning of sustain as a result of previous insulation attack during boost. In those tests where the deposits did not deflect the oxidizer, it could be seen that the deposits from the sustain combustion gases were negligible. This reduction during sustain was attributed to a reduced level of combustion gas circulation and a reduced flow rate of cooling oxidizer, resulting in a higher injector face skin temperature. The injector fix is consistent with this reasoning because a reduction in the mass of material near the injector face will increase the surface temperature of the exposed area.

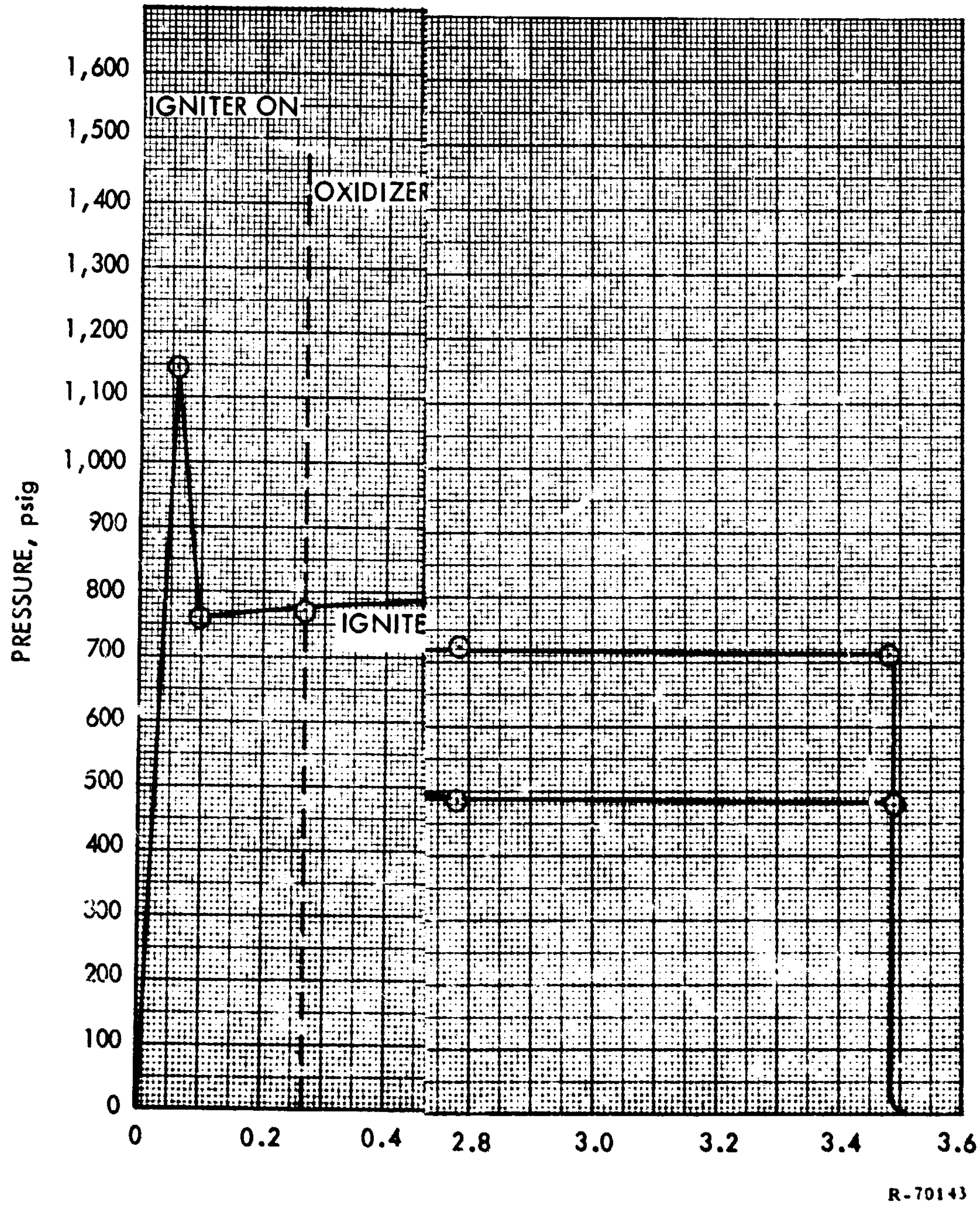
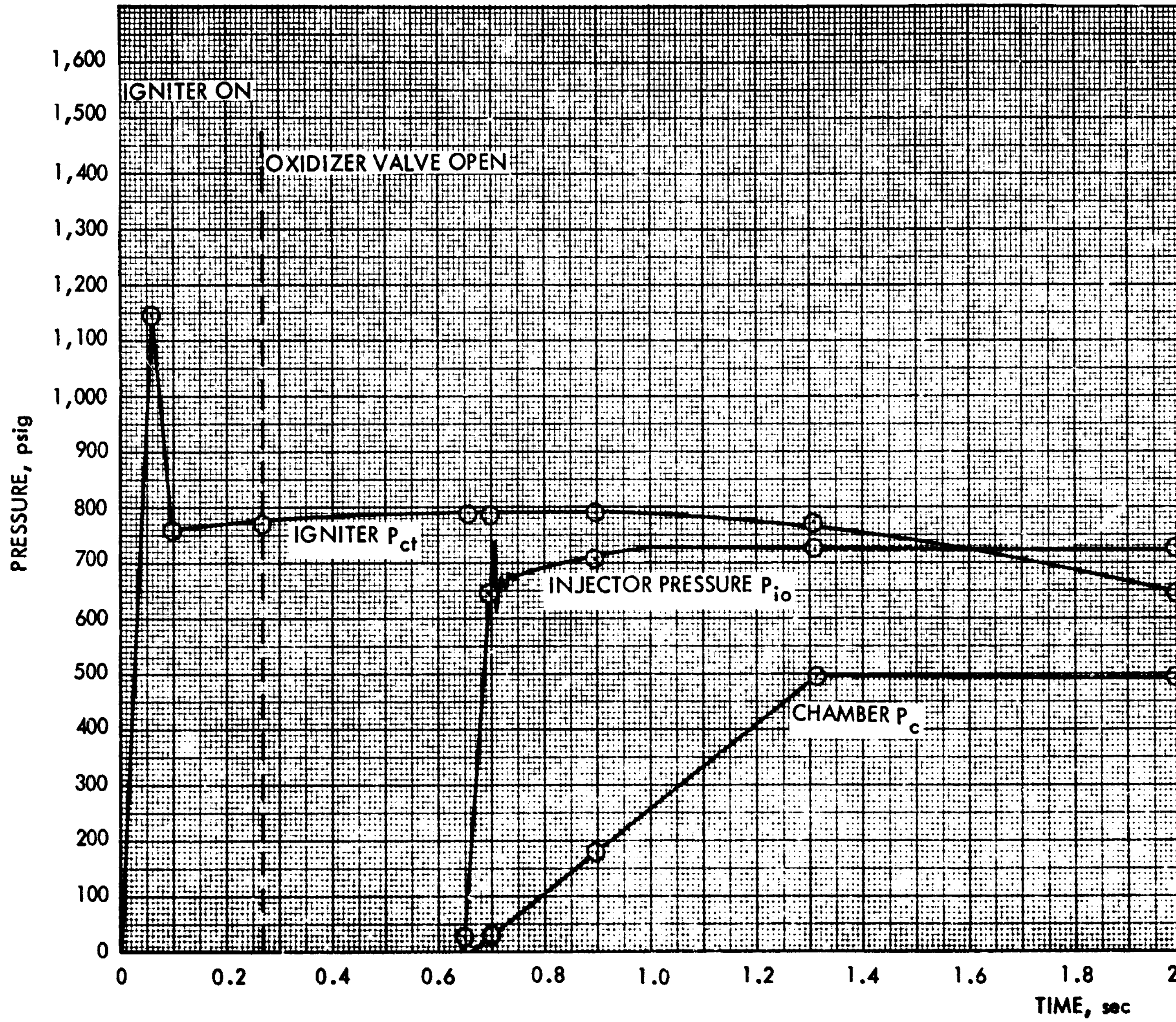


Figure 13. (U) P_{ci}, P_c, P_{io} vs Time, Test No. H3S-39, 10-in. Hybrid, -65° F, 50,000-ft Altitude



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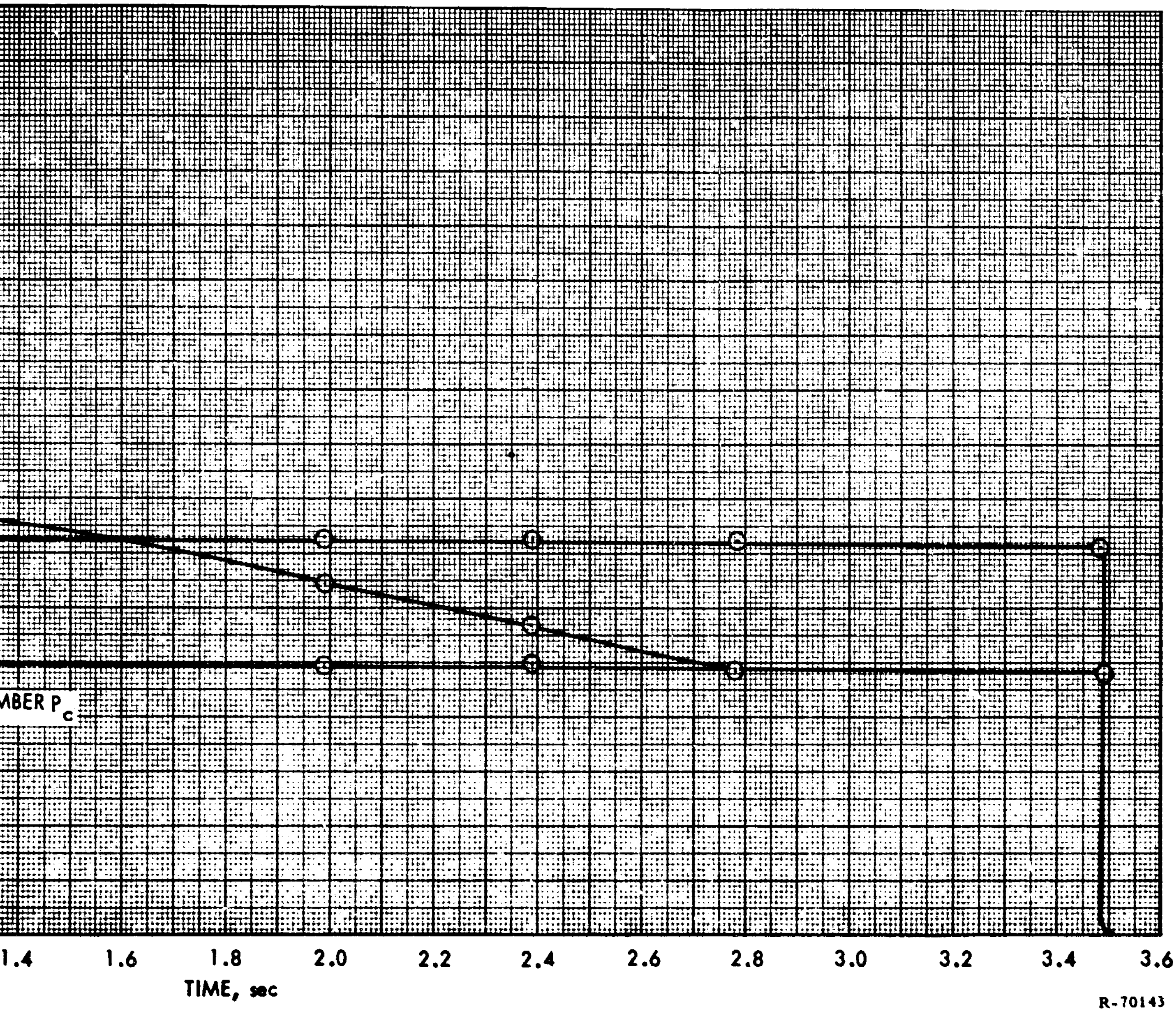

Figure 13. (U) P_{ci}, P_c, P_{io} vs Time, Test No. H3S-39, 10-in. Hybrid, -65° F, 50,000-ft Altitude

SECTION IV

FUTURE WORK

(U) During the next reporting period, the flightweight feed system cold flow tests will be completed and final design drawings will be released. The feed system blowdown efficiencies will be determined and pressure drop measurements will allow final injector flow trimming.

(U) Following the feed system cold flow tests, the system tests will begin with an initial shakedown test utilizing the flightweight feed system in conjunction with a heavyweight TCA. The flight system proof tests will then follow in parallel with the structures test and vibration test.

(U) Prior to the actual proof tests, the flightweight igniter assembly will undergo final qualification tests utilizing hardware taken from delivery item production batches.

APPENDIX I

STRUCTURAL QUALIFICATION OF TCA

Engineering Department 28 September 1966

UNITED TECHNOLOGY CENTER

Sunnyvale, California

Structural Analysis Report

GEN-2

10 INCH HYBRID DRONE, FLIGHT WEIGHT MOTOR CASE

STRUCTURAL ANALYSIS

Prepared by P. F. O'Driscoll
R. D. Bush

Reviewed by:

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Motor Structures

Approved by:

R. A. Jankowski, Section Chief
Structural & Aerothermo Analysis Test

TABLE OF CONTENTS

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1.0 INTRODUCTION

This report presents the structural analysis of the 10" Hybrid Drone, Flight-Weight, Thrust Chamber Case. This report includes an analysis of the injector boss region, the forward 'Y' ring with and without the aluminum adapter ring in place, the aft closure joint, and the hydro-test closure at the exit plane.

This structural analysis report is made to comply with Section 3.4.2 of reference 1.

This analysis is made for the hydro-test load condition : internal pressure and no loads applied through the skirts. The analysis for internal pressure and flight loads applied concurrently, will be presented in Structural Analysis Report GKN-3, "10 inch Hybrid Drone, Thrust Chamber Assembly, Structural Analysis".

2.0 CONCLUSIONS

All components are shown to have positive margins of safety at ultimate pressure, with or without the aluminum adapter ring in place. Further, since the hydrotest closure plate at the exit plane applied a load virtually identical to that of the nozzle insert, this analysis demonstrates the adequacy of the motor case design for motor operation.

The basic case wall is sized by the minimum manufactured thickness of material, and hence, the basic wall margin of safety is high. The margins of safety for the motor case components are listed below:

Injector Boss region:	+0.98
Forward Closure Y-Ring region: (with aluminum adapter ring)	+0.44
Forward Closure Y-Ring region: (without aluminum adapter ring)	+0.45
Aft Closure region:	+0.55
Aft Closure bolts:	+0.78
Exit Plane Ring region:	+4.45
Aluminum Adapter Ring:	+3.16

A more detailed list of margins of safety is given in Section 5.

3.0 LOADS

Loads are taken from Appendix A, "Preliminary Model Specification for a Hybrid Rocket Engine Propulsion System", Contract AF 04(611)-11632. Values of loads obtained from this appendix are summarized at the start of the detailed calculations for the components to which they apply.

4.0 REFERENCES

1. Attachment #1 to Exhibit "A", Contract AF 04(611)-11632. Appendix A, "Preliminary Model Specification for a Hybrid Rocket Engine Prepulsion System"

2. Specification, Steel Forgings, Bars, Plates and Sheets, 18 Percent Nickel Maraging, No. SE 0100. United Technology Center

3. "Allowable Stresses and Interaction Equations for Thin Cylinders," STM #5, Convair (Astronautics) Division, General Dynamics Corporation. 7-29-60

4. Shanley, "Strength of Materials."

5. "Strength of Metal Aircraft Elements," MIL-HDBK-5. D.O.D. March 1961

5.0 DETAILED CALCULATIONS

For analysis purposes, the motor case is divided into four regions, as shown in Figure 1. They are:

i) Injector boss region

ii) Forward Closure Y Ring region

iii) Aft Closure region

iv) Exit Plane Ring

As an approximate analysis for the eccentric injector boss the region is analyzed first as an axi-symmetric shell without a boss, and secondly as an axi-symmetric shell with the boss cross-section included.

The forward Y ring is analyzed both with and without the aluminum adapter ring in place.

The exit plane ring is analyzed with [illegible] a bearing load on the ring which approximates both the hydrotest closure load and also the throat insert blow-out load.

The method of analysis used for shells is a computer program which is outlined in Appendix A.

The components analyzed are detailed on UTC Drawings No. CO2236, CO2406, CO2177 and CO2219.

10" HYBRID MOTOR COMBUSTION CHAMBER

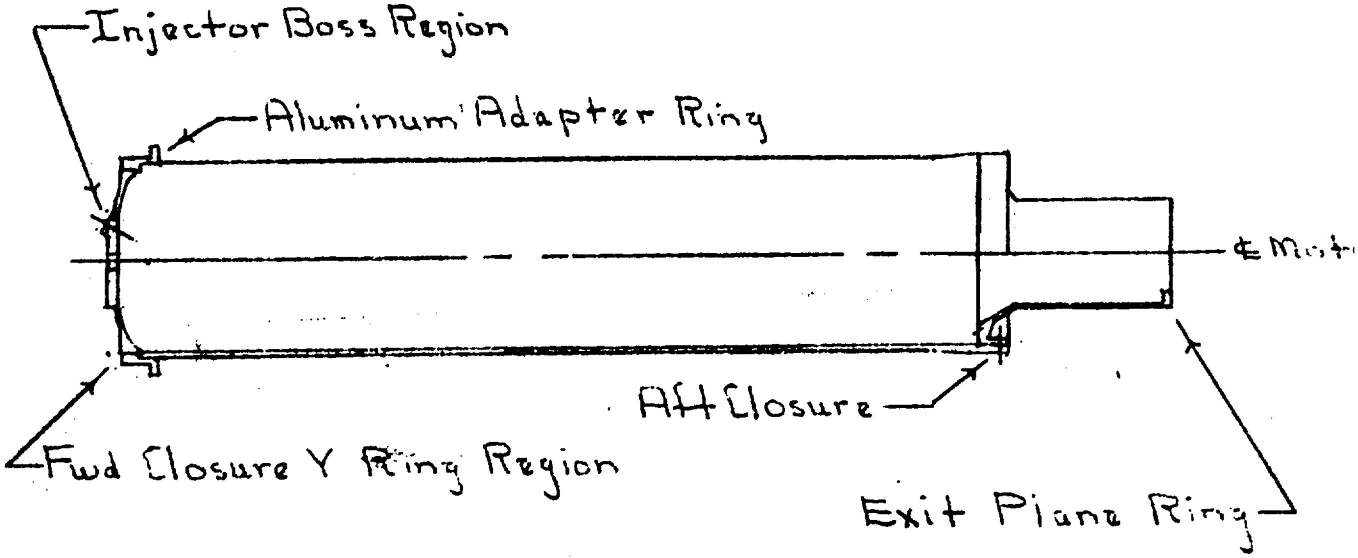


FIGURE 1 NOMENCLATURE

MATERIAL 18 % NICKEL MARAGING STEEL
TYPE I - 200 GRADE

F_{tu} = 210,000 PSI

F_{ty} = 200,000 PSI

United Techology Center, Specification, Steel Forgings, Bars, Plates and Sheets, 18 Percent Nickel Maraging, No. SE0100.

MARGINS OF SAFETY

ITEM	"S"	f_{max}	TYPE	F_{TU}	M.S.
INJECTOR BOSS REGION					
SHELL 1	.35	54,000	MI	210,000	+ 2.89
SHELL 2	.30	105,000	MO	210,000	+ 1.00
INJECTOR BOSS REGION (NO BOSS AREA)					
SHELL 1	.20	106,000	MO	210,000	+ 0.98
FORWARD CLOSURE 'Y' RING REGION					
SHELL 1	0	57,500	CO	210,000	+ 2.65
SHELL 2	.42	146,000	MI	210,000	+ 0.45
FORWARD CLOSURE 'Y' RING REGION (WITH ALUMINUM ADAPTOR RING)					
SHELL 1	2.9	89,000	MI	210,000	+ 1.36
SHELL 2	.42	146,000	MI	210,000	+ 0.44
AFT CLOSURE					
SHELL 1	2.45	69,500	CO	210,000	+ 2.02
SHELL 2	1.00	80,000	MI	210,000	+ 1.63
SHELL 3	1.20	136,000	CO	210,000	+ 0.55
SHELL 4	0	131,000	CI	210,000	+ 0.60
BOLT					
EXIT PLANE RING					
SHELL 1	1.15	38,500	CO	210,000	+ 4.45

"S" : DISTANCE ALONG SHELL

TYPE : M – MERIDIONAL , C – CIRCUMFERENTIAL
I – INSIDE , O – OUTSIDE

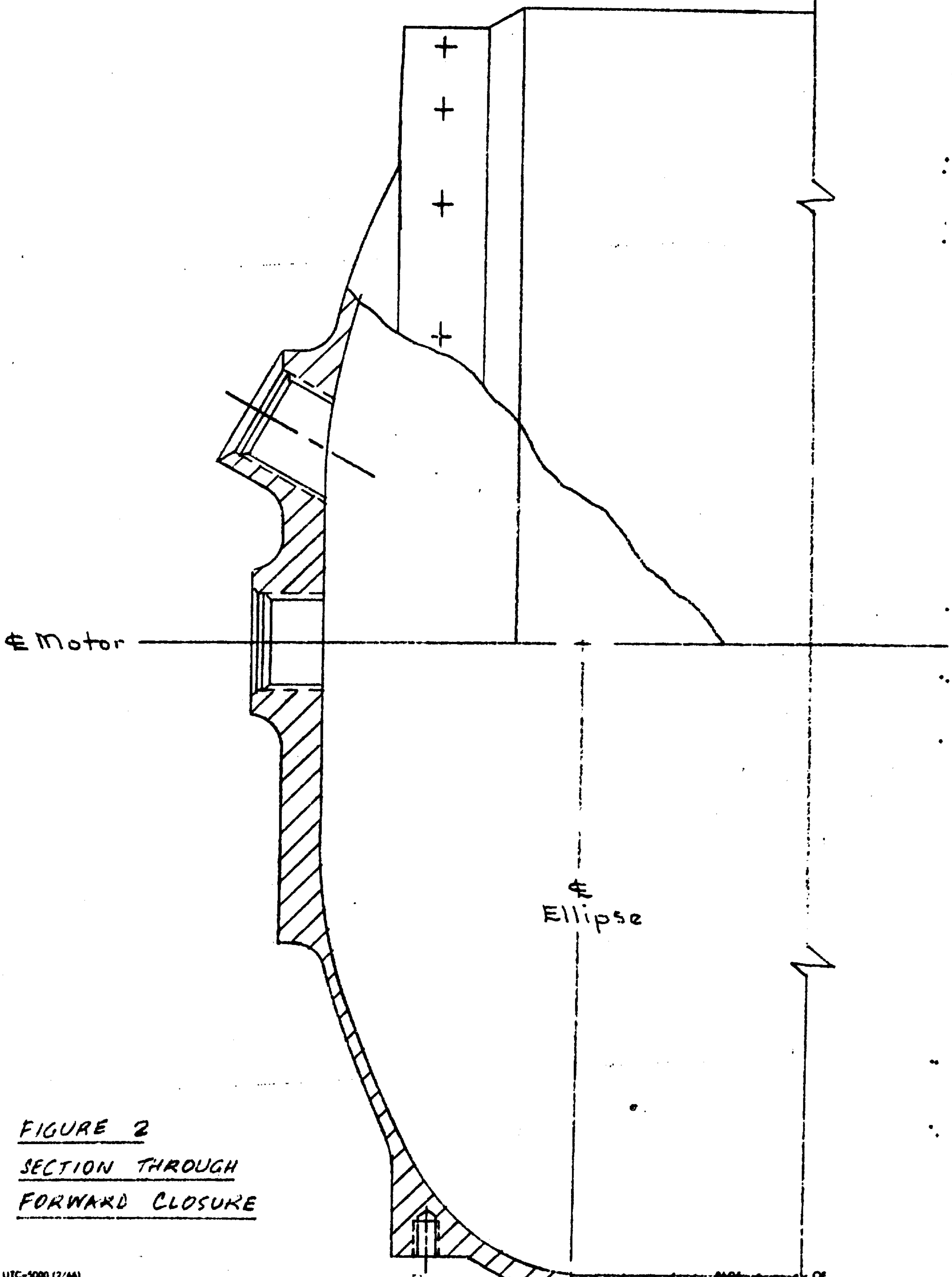


FIGURE 2
SECTION THROUGH
FORWARD CLOSURE

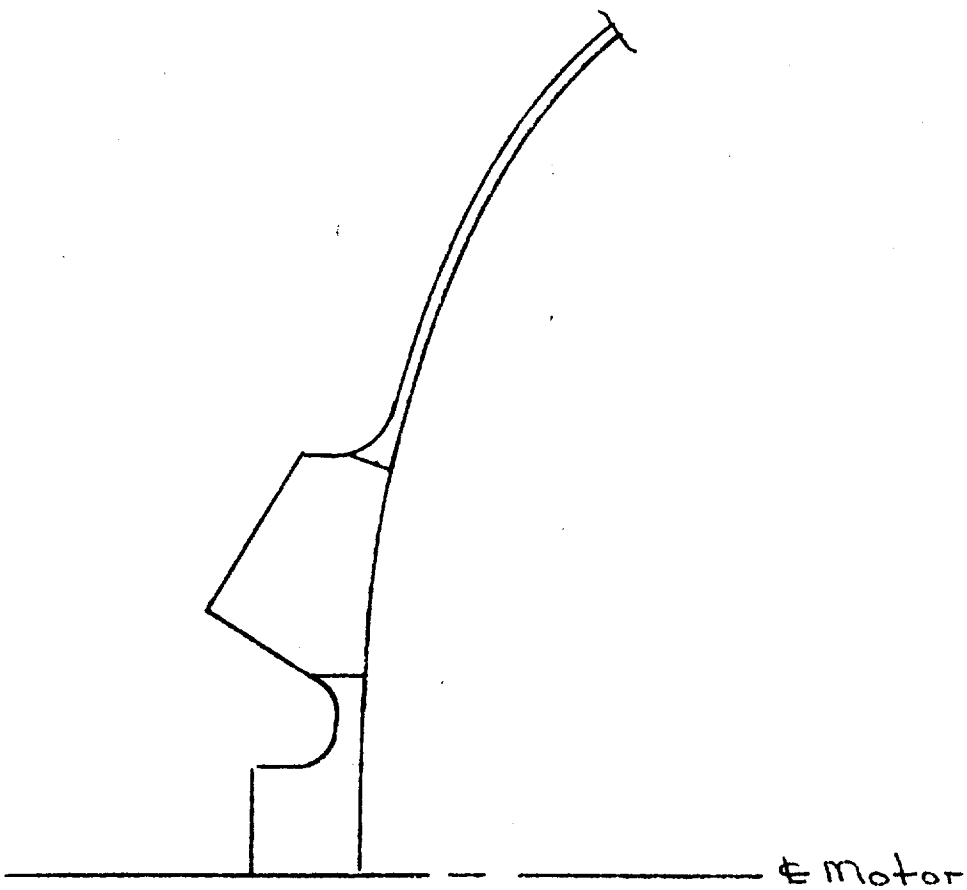


FIGURE 3

INJECTOR BOSS REGION

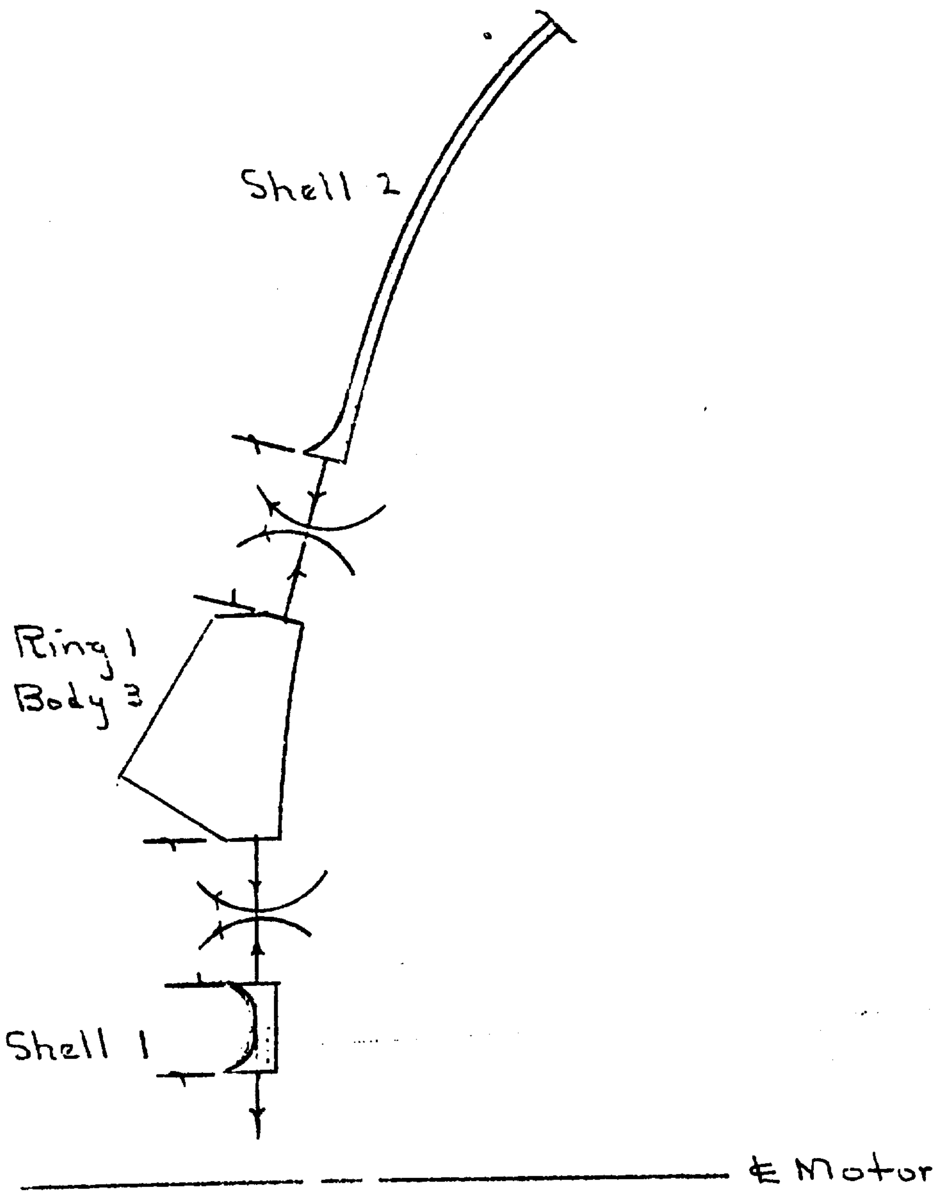


FIGURE 4

INJECTOR BOSS REGION

10 IN HYBRID, THRUST CHAMBER, INJECTOR BOSS REGION 6 OCT. 66

Fx, Fy, Mcg, 1106, 0, 0,

$$F_x = (2.2600 - \overset{1.2150}{1.0450})\ 910 = 1106 \text{ LB}$$

$$F_y = 0$$

$$M_{CG} = 0$$

B.C.

5,
1, 1, 1, 2, 2,
0, 0, 0, 1, 1,
2, 4, 5, 3, 4,
0, 951, 4997, 0, 0,

$$\beta_1 = 0$$

$$Q_1 = 1.045(910) = 951 \text{ LB}$$

$$N_1 = \frac{P R_2}{2} = \frac{910}{2}(10.9827) = 4997 \text{ LB}$$

THE VALUE OF ULTIMATE PRESSURE IS 910 psi

THIS IS OBTAINED IN THE FOLLOWING MANNER :

CHAMBER PRESSURE , P_c , FROM TESTS : 550 psi.

MEOP = 550 × 1.1 = 605 psi

ULTIMATE PRESSURE = 605 × 1.5 = 910 psi.

United Technology Center — DIVISION OF UNITED AIRCRAFT CORPORATION

PREPARED BY [illegible] DATE [illegible]

REVIEWED BY DATE

Shell 1

INPUT VALUES FOR UNIT ANALYSIS
OF AN AXISYMMETRIC THIN SHELL PROJ. NO. ______

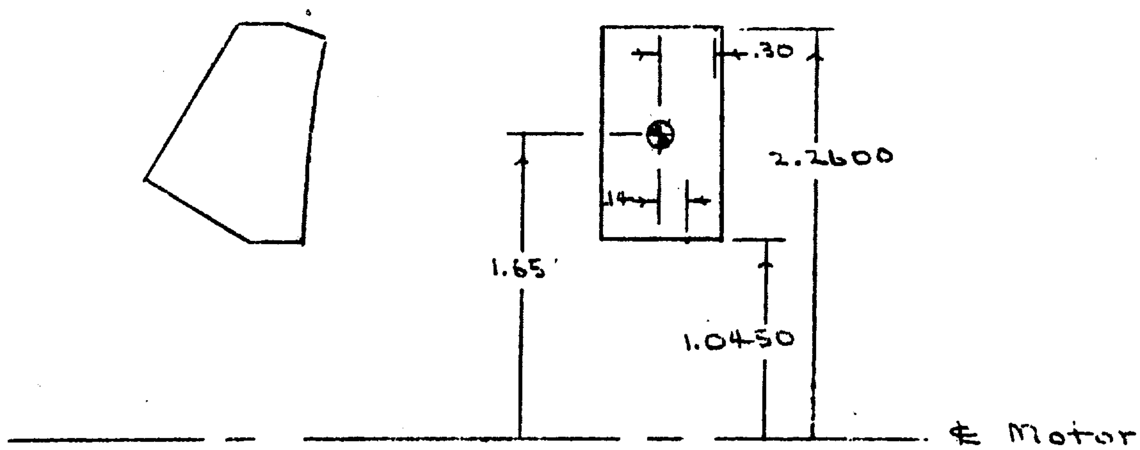
SHELL LENGTH .50 . POISSON'S RATIO 0.3 .

YOUNGS MODULUS 2.65×10^7 NO. TAYLOR SERIES 5 . NO. SEGMENTS 50 .

MERIDIONAL STATION	R_1	R_2	THICKNESS	PHI
0	10.8744	10.9827	.240	2.8[illegible]
.05	10.8436	10.9722	.185	3.13[illegible]
.10	10.8102	10.9610	.141	3.3975
.15	10.7741	10.9488	.113	3.6629
.20	10.7355	10.9357	.100	3.9292
.25	10.6942	10.9216	.100	4.1765
.30	10.6503	10.9067	.100	4.4644
.35	10.6033	10.8909	.113	4.7344
.40	10.5542	10.8740	.141	5.0051
.45	10.5034	10.8563	.185	5.[illegible]
.50	10.4494	10.8377	.240	5.5505

N-225 (5/63)

INJECTOR BOSS REGION



RLI = 1.0481
PHILI = 5.5505
XLI = -.14

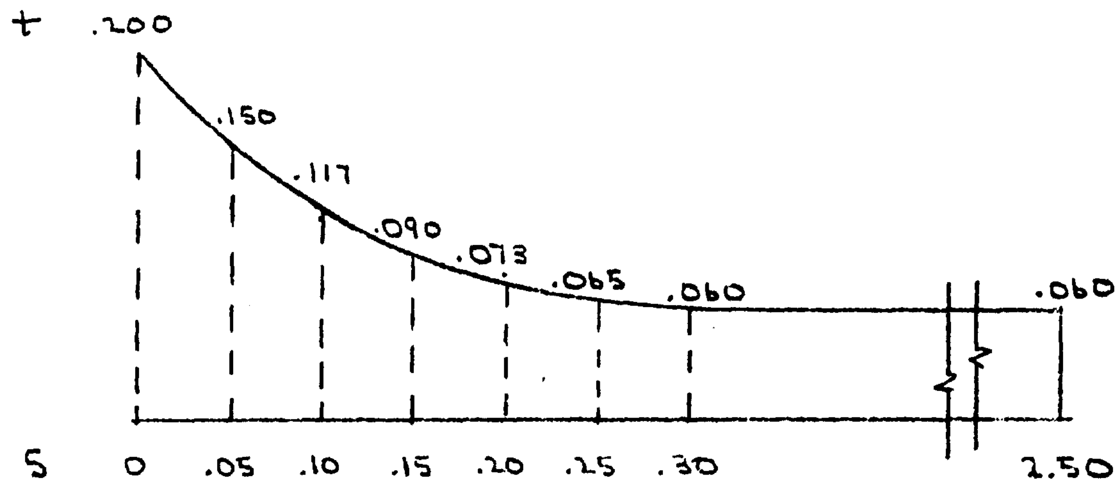
RLO = 0
PHILO = 0
XLO = 0

RRI = 0
PHIRI = 0
XRI = 0

RRO = 2.2600
PHIRO = 13.712
XRO = .30

R_{CG} = 1.65
$A = 1.17(.64) = .7488 \text{ IN}^2$
$I = \frac{1.17}{12}(.64)^3 = .02556 \text{ IN}^4$
$E = 2.65 \times 10^7$ PSI

Shell 2



$$\beta = \frac{1.285}{\sqrt{R_2 t}} = \frac{1.285}{\sqrt{8(.060)}} = \frac{1.285}{\sqrt{.48}} = \frac{1.285}{.692}$$

$$\beta = 1.87$$

$$\lambda = 5.00/1.87 = 2.63$$

Shell 2

INPUT VALUES FOR UNIT ANALYSIS
OF AN AXISYMMETRIC THIN SHELL PROJ. NO. ________

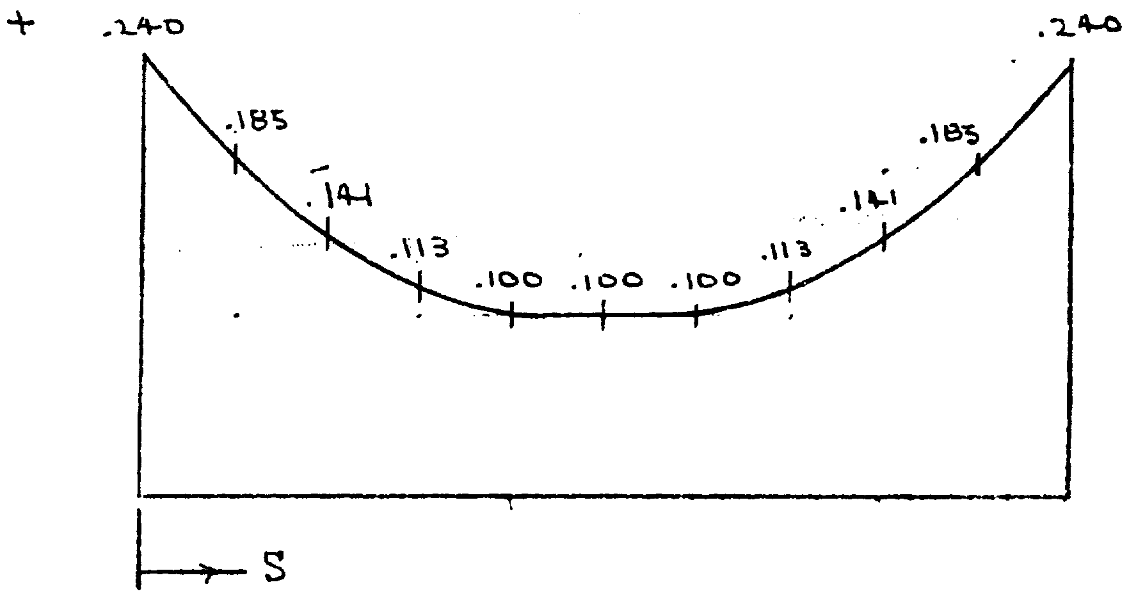
SHELL LENGTH 2.50. POISSON'S RATIO 0.3.

YOUNGS MODULUS 2.65×10^7. NO. TAYLOR SERIES 5. NO. SEGMENTS 50.

MERIDIONAL STATION	R_1	R_2	THICKNESS	PHI
1.60	4.1766	7.6922	.060	29.1902
1.70	3.9329	7.5396		30.6017
1.80	3.6923	7.3826		32.1027
1.90	3.4559	7.2215		33.7039
2.00	3.2244	7.0565		35.4172
2.10	2.9988	6.8880		37.2562
2.20	2.7801	6.7163		39.2369
2.30	2.5694	6.5421		41.3715
2.40	2.3677	6.3663		43.6948
2.50	2.1762	6.1898	.060	46.2138

N-225 (5/63)

Shell 1



$\phi = 13.712^\circ = 13^\circ\ 42.72'$

$\sin 13^\circ\ 42.72' = .23704$

$R_2 = 9.5342$

$RRO = R_2 \sin\phi = 9.5342(.23704) = 2.2600$

10 IN HYBRID,THRUST CHAMBER,FWD Y RING,ELLIPSE PROPS R.D. BUSH 5 AUG 66

INPUT DATA

A = 4.90000 B = 2.30000 X = 2.26000 DELTAS = 0.05000

GEOMETRIC PROPERTIES - ELLIPSOID OF REVOLUTION

NDELTAS	R1	R2	PHI
0.00000000	7.95286696E+00	9.53419701E+00	13.71199071
0.05000000	7.85017765E+00	9.49298317E+00	14.07431601
0.10000000	7.74593771E+00	9.45077773E+00	14.44144222
0.15000000	7.640[illegible]309E+00	9.40757438E+00	14.81357223
0.20000000	7.53299104E+00	9.36336672E+00	15.19091806
0.25000000	7.42438007E+00	9.31814823E+00	15.57370140
0.30000000	7.31441003E+00	9.27191234E+00	15.96215430
0.35000000	7.20313207E+00	9.22465237E+00	16.35651974
0.40000000	7.09059873E+00	9.17636160E+00	16.75705243
0.45000000	6.97686390E+00	9.12703326E+00	17.16401948
0.50000000	6.86198291E+00	9.07666054E+00	17.57770129
0.55000000	6.7460[illegible]25[illegible]E+00	9.02523663E+00	17.99839239
0.60000000	6.62901099E+00	8.97275471E+00	18.42640239
0.65000000	6.51103801E+00	8.91920802E+00	18.86205699
0.70000000	6.39215487E+00	8.86458983E+00	19.30569909
0.75000000	6.27242438E+00	8.80889353E+00	19.75768995
0.80000000	6.15191099E+00	8.75211262E+00	20.21841046
0.85000000	6.03068076E+00	8.69424076E+00	20.68826252
0.90000000	5.90880142E+00	8.63527185E+00	21.16767049
0.95000000	5.78634243E+00	8.57520004E+00	21.65708281
1.00000000	5.66337498E+00	8.51401979E+00	22.15697371
1.05000000	5.53997207E+00	8.45172597E+00	22.66784506
1.10000000	5.41620853E+00	8.38831392E+00	23.19022835
1.15000000	5.29216106E+00	8.32377950E+00	23.72468690
1.20000000	5.16790832E+00	8.25811924E+00	24.27181816
1.25000000	5.04353090E+00	8.19133042E+00	24.83225625
1.30000000	4.91911145E+00	8.12341119E+00	25.40667468
1.35000000	4.79473469E+00	8.05436073E+00	25.99578925
1.40000000	4.67048745E+00	7.98417938E+00	26.60036130
1.45000000	4.54645876E+00	7.91286885E+00	27.22120103
1.50000000	4.42273987E+00	7.84043240E+00	27.85917124
1.55000000	4.29942436E+00	7.76687508E+00	28.51519123
1.60000000	4.17660812E+00	7.69220398E+00	29.19024107
1.65000000	4.05438947E+00	7.61642853E+00	29.88536611
1.70000000	3.93286920E+00	7.53956084E+00	30.60168178
1.75000000	3.81215063E+00	7.46161609E+00	31.34037879
1.80000000	3.69233966E+00	7.38261291E+00	32.10272851
1.85000000	3.57354485E+00	7.30257392E+00	32.89008868
1.90000000	3.45587743E+00	7.22152623E+00	33.70390942
1.95000000	3.33945144E+00	7.13950212E+00	34.54573935
2.00000000	3.22438368E+00	7.05653967E+00	35.41723194
2.05000000	3.11079383E+00	6.97268361E+00	36.32015181
2.10000000	2.99880447E+00	6.88798616E+00	37.25638098
2.15[illegible]	2.[illegible]	6.80250806E+00	38.22792482
[illegible]	2.78013212E+00	6.71631971E+00	39.23691746
2.25000000	2.67376900E+00	6.62950235E+00	40.28562627
2.30000000	2.56940610E+00	6.54214953E+00	41.37645514
2.35000000	2.46736073E+00	6.45436862E+00	42.51194583
2.40000000	2.36771306E+00	6.36628249E+00	43.69477685
2.45[illegible]	2.27060611E+00	[illegible].27803140E+00	44.927[illegible]91

2.50000000	2.17618558D+00	6.18977494D+00	46.21382596
2.55000000	2.08459974D+00	6.10169426D+00	47.55602049
2.60000000	1.99599920D+00	6.01399418D+00	48.95747161
2.65000000	1.91053670D+00	5.92690561D+00	50.42136410
2.70000000	1.82836675D+00	5.84068773D+00	51.95089646
2.75000000	1.74964525D+00	5.75563021D+00	53.54922581
2.80000000	1.67452903D+00	5.67205512D+00	55.21939733
2.85000000	1.60317524D+00	5.59031845D+00	56.96425611
2.90000000	1.53574069D+00	5.51081096D+00	58.78633970
2.95000000	1.47238103D+00	5.43395812D+00	60.68775035
3.00000000	1.41324978D+00	5.36021889D+00	62.67000720
3.05000000	1.35849733D+00	5.29008292D+00	64.73388072
3.10000000	1.30826966D+00	5.22406580D+00	66.87921409
3.15000000	1.26270700D+00	5.16270226D+00	69.10473964
3.20000000	1.22194242D+00	5.10653677D+00	71.40790184
3.25000000	1.18610017D+00	5.05611185D+00	73.78470215
3.30000000	1.15529411D+00	5.01195391D+00	76.22958365
3.35000000	1.12962598D+00	4.97455732D+00	78.73537496
3.40000000	1.10918380D+00	4.94436727D+00	81.29331132
3.45000000	1.09404032D+00	4.92176257D+00	83.89314664
3.50000000	1.08425160D+00	4.90703972D+00	86.52336228
1.05905730	2.83094227D+00	6.75698913D+00	38.75697992

PROCESSOR: 0.090 MINUTES
INPUT/OUTPUT: 0.121 MINUTES
ELAPSED TIME: 0.112 MINUTES

10 IN HYBRID,THRUST CHAMBER,INJECTOR BOSS REGION 6 OCT, 1966

SHELL #1 END PLATE

SHELL UNIT ANALYSIS

SHELL NO. 1, CONFIGURATION NO. 1

INPUT IS:

TAYLORS SERIES EXPANSIONS OF 5 TERMS ARE USED TO SOLVE THE DIFFERENTIAL EQUATIONS SIMULTANEOUSLY.

THE 0.5000 INCH LONG SHELL SECTION IS DIVIDED INTO 50 SEGMENTS EACH OF WHICH IS 0.0100 INCHES LONG.

MODULUS OF ELASTICITY, E = 2.65000P+07

POISSON S RATIO, NU = 0.3000

MERIDIONALLY VARING PARAMETER FUNCTIONS:

```
    RADIUS 1 =   1.0874P+01  1.0844P+01  1.0810P+01  1.0774P+01  1.0735P+01  1.0694P+01  1.0650P+01
           S =   0.0000P+00  5.0000P-02  1.0000P-01  1.5000P-01  2.0000P-01  2.5000P-01  3.0000P-01

                 1.0604P+01  1.0555P+01  1.0503P+01  1.0449P+01
                 3.5000P-01  4.0000P-01  4.5000P-01  5.0000P-01


    RADIUS 2 =   1.0983P+01  1.0972P+01  1.0961P+01  1.0949P+01  1.0936P+01  1.0922P+01  1.0907P+01
           S =   0.0000P+00  5.0000P-02  1.0000P-01  1.5000P-01  2.0000P-01  2.5000P-01  3.0000P-01

                 1.0891P+01  1.0874P+01  1.0856P+01  1.0838P+01
                 3.5000P-01  4.0000P-01  4.5000P-01  5.0000P-01


   THICKNESS =   2.4000P-01  1.8500P-01  1.4100P-01  1.1300P-01  1.0000P-01  1.0000P-01  1.0000P-01
           S =   0.0000P+00  5.0000P-02  1.0000P-01  1.5000P-01  2.0000P-01  2.5000P-01  3.0000P-01

                 1.1300P-01  1.4100P-01  1.8500P-01  2.4000P-01
                 3.5000P-01  4.0000P-01  4.5000P-01  5.0000P-01


         PHI =   2.8691P+00  3.1324P+00  3.3975P+00  3.6629P+00  3.9292P+00  4.1965P+00  4.4649P+00
           S =   0.0000P+00  5.0000P-02  1.0000P-01  1.5000P-01  2.0000P-01  2.5000P-01  3.0000P-01

                 4.7344P+00  5.0051P+00  5.2771P+00  5.5505P+00
                 3.5000P-01  4.0000P-01  4.5000P-01  5.0000P-01
```

SHELL #2 CLOSURE DOME (ELLIPTICAL)

SHELL UNIT ANALYSIS

SHELL NO. 2, CONFIGURATION NO. 1

INPUT (S)

TAYLORS SERIES EXPANSIONS OF 5 TERMS ARE USED TO SOLVE THE DIFFERENTIAL EQUATIONS SIMULTANEOUSLY.

THE 2.5000 INCH LONG SHELL SECTION IS DIVIDED INTO 50 SEGMENTS EACH OF WHICH IS 0.0500 INCHES LONG.

MODULUS OF ELASTICITY, E = 2.65000E+07

POISSON S RATIO, MU = 0.3000

MERIDIONALLY VARING PARAMETER FUNCTIONS:

RADIUS 1 =	7.9529E+00	7.8502E+00	7.7459E+00	7.6402E+00	7.5330E+00	7.4244E+00	7.3144E+00
S =	0.0000E+00	5.0000E-02	1.0000E-01	1.5000E-01	2.0000E-01	2.5000E-01	3.0000E-01
	7.0906E+00	6.8620E+00	6.6290E+00	6.3922E+00	6.1519E+00	5.9088E+00	5.6634E+00
	4.0000E-01	5.0000E-01	6.0000E-01	7.0000E-01	8.0000E-01	9.0000E-01	1.0000E+00
	5.4162E+00	5.1679E+00	5.0435E+00	4.9191E+00	4.7947E+00	4.6705E+00	4.5465E+00
	1.1000E+00	1.2000E+00	1.2500E+00	1.3000E+00	1.3500E+00	1.4000E+00	1.4500E+00
	4.4227E+00	4.1766E+00	3.9329E+00	3.6923E+00	3.4559E+00	3.2244E+00	2.9988E+00
	1.5000E+00	1.6000E+00	1.7000E+00	1.8000E+00	1.9000E+00	2.0000E+00	2.1000E+00
	2.7801E+00	2.5694E+00	2.3677E+00	2.1762E+00			
	2.2000E+00	2.3000E+00	2.4000E+00	2.5000E+00			

RADIUS 2 =	9.5342E+00	9.4930E+00	9.4508E+00	9.4076E+00	9.3634E+00	9.3181E+00	9.2719E+00
S =	0.0000E+00	5.0000E-02	1.0000E-01	1.5000E-01	2.0000E-01	2.5000E-01	3.0000E-01
	9.1764E+00	9.0767E+00	8.9728E+00	8.8646E+00	8.7521E+00	8.6353E+00	8.5140E+00
	4.0000E-01	5.0000E-01	6.0000E-01	7.0000E-01	8.0000E-01	9.0000E-01	1.0000E+00
	8.3883E+00	8.2581E+00	8.1913E+00	8.1234E+00	8.0544E+00	7.9842E+00	7.9129E+00
	1.1000E+00	1.2000E+00	1.2500E+00	1.3000E+00	1.3500E+00	1.4000E+00	1.4500E+00
	7.8404E+00	7.6922E+00	7.5396E+00	7.3826E+00	7.2215E+00	7.0565E+00	6.8880E+00
	1.5000E+00	1.6000E+00	1.7000E+00	1.8000E+00	1.9000E+00	2.0000E+00	2.1000E+00
	6.7163E+00	6.5421E+00	6.3663E+00	6.1896E+00			
	2.2000E+00	2.3000E+00	2.4000E+00	2.5000E+00			

```
THICKNESS =     2.0000P-01  1.5000P-01  1.1700P-01  9.0000P-02  7.3000P-02  6.5000P-02  6.0000P-02
        S =     0.0000P+00  5.0000P-02  1.0000P-01  1.5000P-01  2.0000P-01  2.5000P-01  3.0000P-01

                6.0000P-02
                2.5000P+00


      PHI =     1.3712P+01  1.4074P+01  1.4441P+01  1.4814P+01  1.5191P+01  1.5574P+01  1.5952P+01
        S =     0.0000P+00  5.0000P-02  1.0000P-01  1.5000P-01  2.0000P-01  2.5000P-01  3.0000P-01

                1.6757P+01  1.7578P+01  1.8426P+01  1.9306P+01  2.0218P+01  2.1168P+01  2.2157P+01
                4.0000P-01  5.0000P-01  6.0000P-01  7.0000P-01  8.0000P-01  9.0000P-01  1.0000P+00

                2.3190P+01  2.4272P+01  2.4832P+01  2.5407P+01  2.5996P+01  2.6600P+01  2.7221P+01
                1.1000P+00  1.2000P+00  1.2500P+00  1.3000P+00  1.3500P+00  1.4000P+00  1.4500P+00

                2.7859P+01  2.9190P+01  3.0602P+01  3.2103P+01  3.3704P+01  3.5417P+01  3.7256P+01
                1.5000P+00  1.6000P+00  1.7000P+00  1.8000P+00  1.9000P+00  2.0000P+00  2.1000P+00

                3.9237P+01  4.1377P+01  4.3695P+01  4.6214P+01
                2.2000P+00  2.3000P+00  2.4000P+00  2.5000P+00
```

SHELL/RING BOUNDRY CONDITIONS AND FORCES

CASE NO. 1, CONFIGURATION NO. 1

SHELL NO. 1

BET-L = 0.0000E+00

Q-L = 9.5100E+02

N-L = 0.0000E+00

PRESSURE = 9.1000E+02

SHELL NO. 2

M-R = 0.0000E+00

Q-R = 0.0000E+00

PRESSURE = 9.1000E+02

RING NO. 1

FX = 1.1060E+03 FY = 0.0000E+00 MCG = 0.0000E+00

SHELL/RING DISCONTINUITY DEFORMATION AND FORCE SOLUTIONS

CASE NO. 1, CONFIGURATION NO. 1

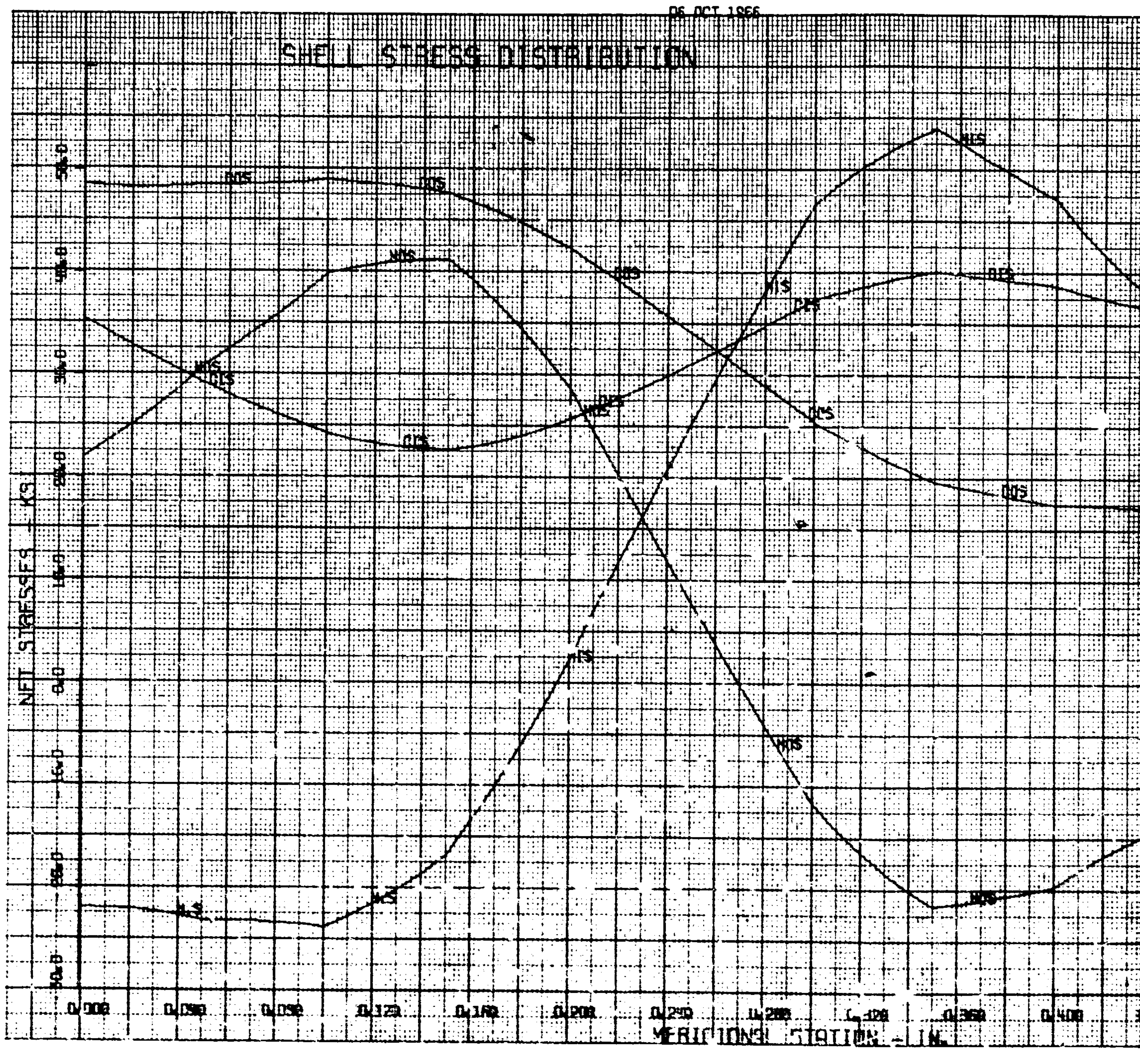
SHELL NO. 1	LEFT END	RIGHT END
DELTA	8.711263E-04	8.819095E-04
BETA	0.000000E+00	1.229704E-03
M	-2.104973E+02	1.677798E+02
Q	9.510000E+02	6.309375E+02
N	0.000000E+00	2.231945E+03

SHELL NO. 2	LEFT END	RIGHT END
DELTA	1.078662E-03	-9.823903E-03
BETA	1.229704E-03	-1.726450E-02
M	-2.534049E+01	0.000000E+00
Q	3.169838E+01	0.000000E+00
N	4.926721E+03	2.934761E+03

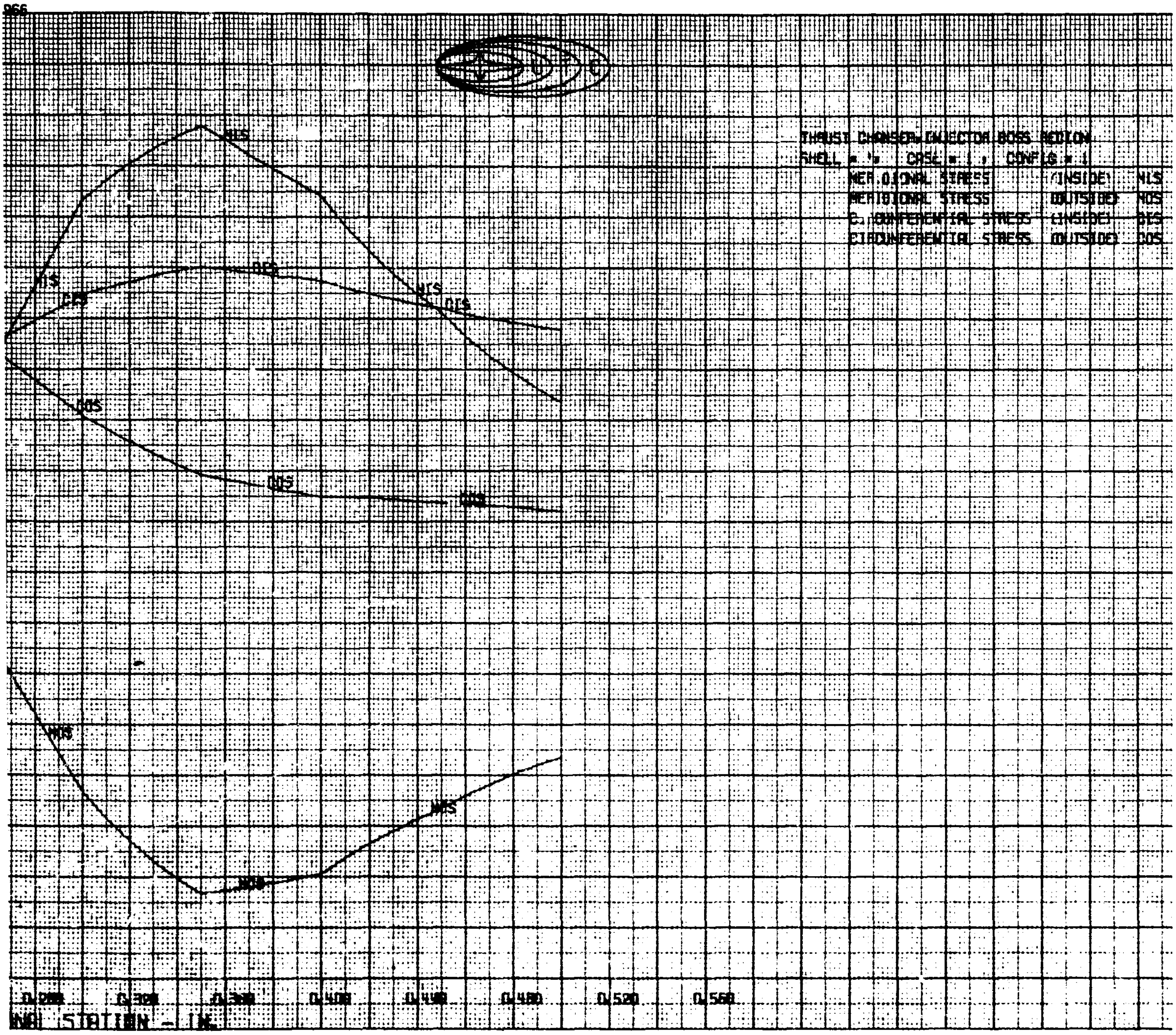
RING NO. 1	LEFT INSIDE	LEFT OUTSIDE	RIGHT INSIDE	RIGHT OUTSIDE
DELTA	8.819095E-04	0.000000E+00	0.000000E+00	1.078662E-03
BETA	1.229704E-03	0.000000E+00	0.000000E+00	1.229704E-03
M	1.677798E+02	0.000000E+00	0.000000E+00	-2.534049E+01
Q	6.309375E+02	0.000000E+00	0.000000E+00	3.169838E+01
N	2.231945E+03	0.000000E+00	0.000000E+00	4.926721E+03

DEL-CG = 7.097509E-04 BETA-CG = 1.229704E-03

M-NET = 3.059423E+02 Q-NET = 5.173087E+03



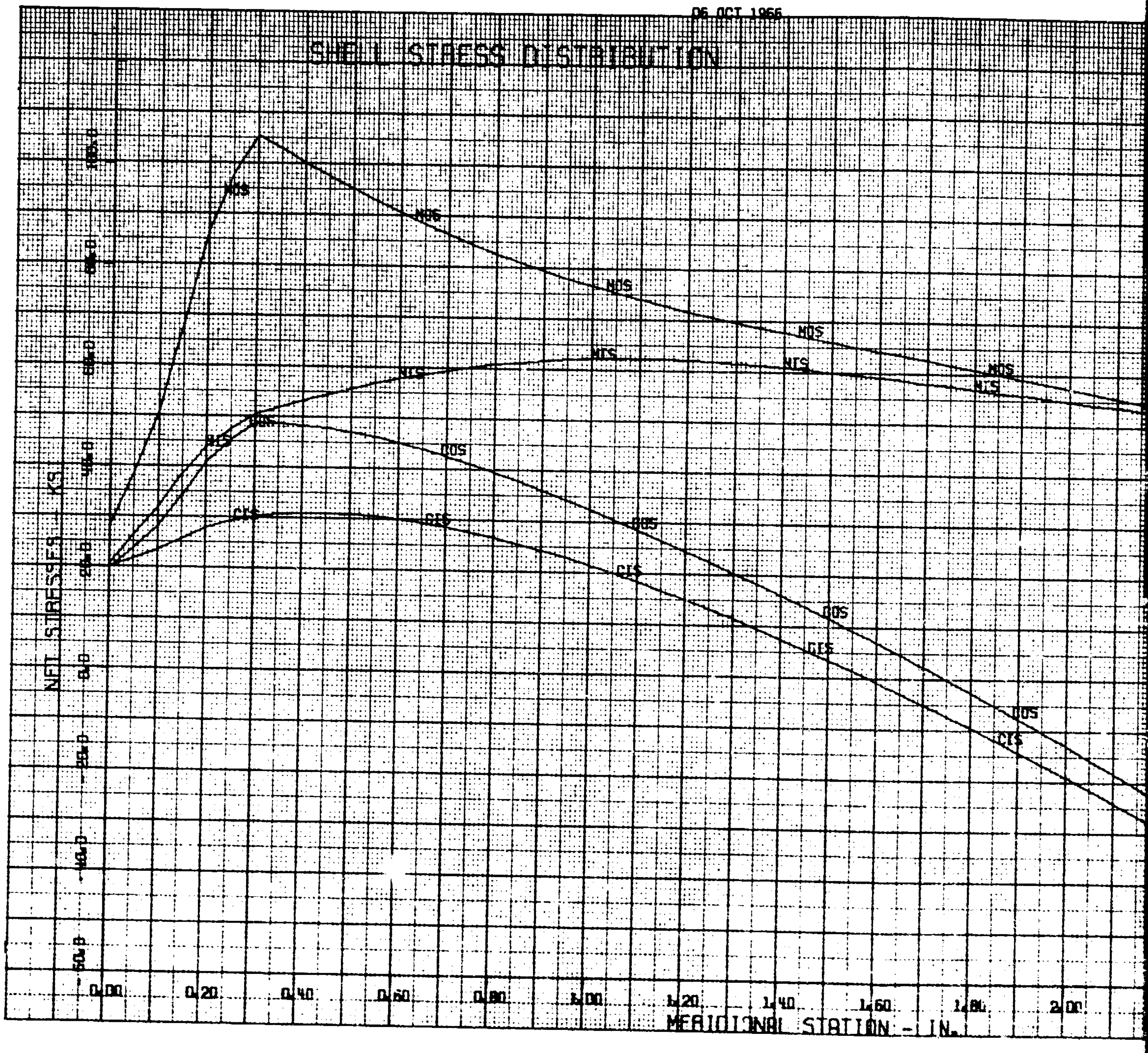
06 OCT 1966
SHELL STRESS DISTRIBUTION
NET STRESSES - KSI
MERIDIONAL STATION - IN.



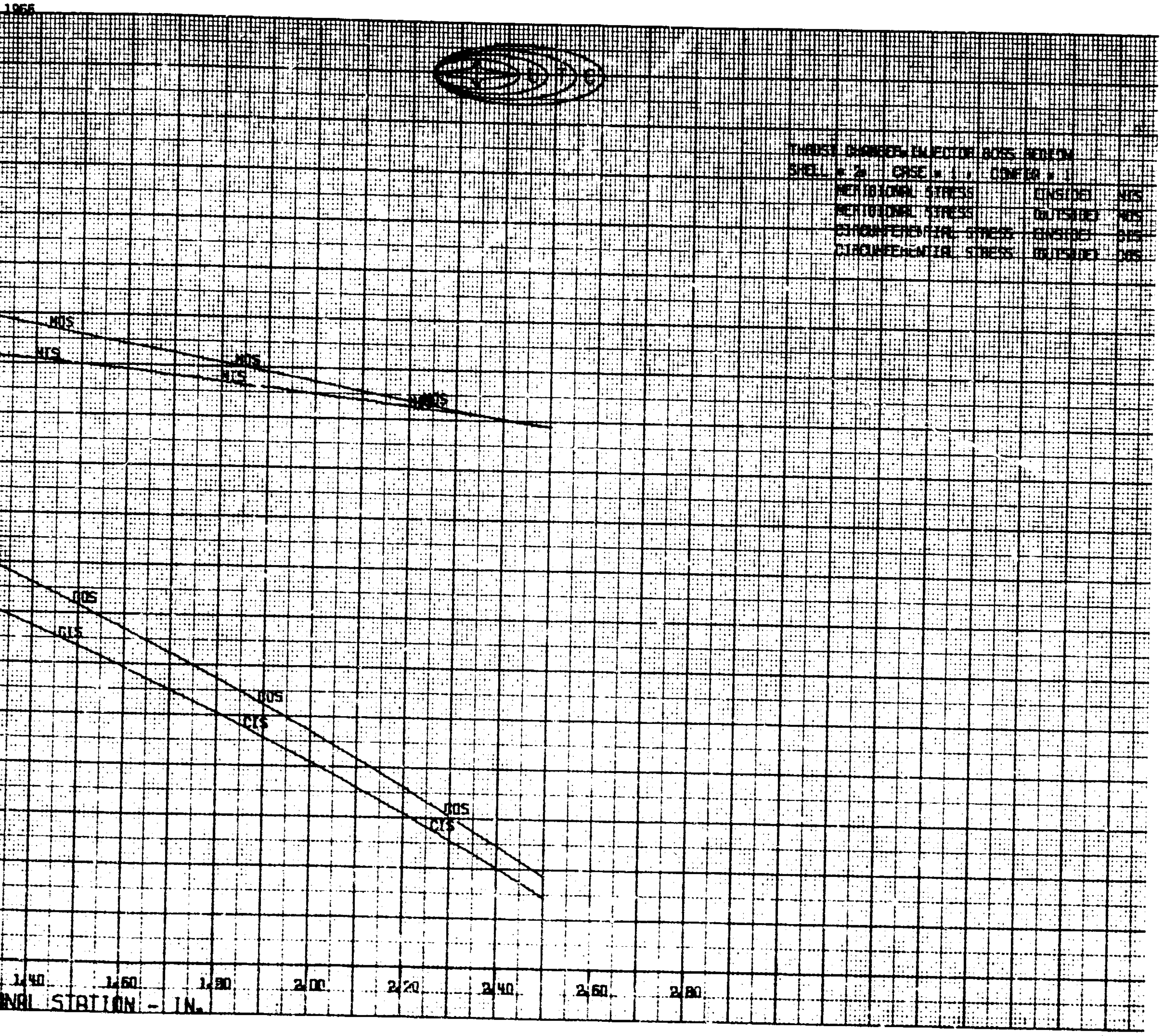
THRUST CHAMBER-INJECTOR BOSS REGION
SHELL = 5, CASE = 1, CONFIG = 1
MERIDIONAL STRESS (INSIDE) MIS
MERIDIONAL STRESS (OUTSIDE) MOS
CIRCUMFERENTIAL STRESS (INSIDE) CIS
CIRCUMFERENTIAL STRESS (OUTSIDE) COS
MIS
CIS
COS
MOS
0.440
0.480
0.520
0.560
STATION - IN.

63/64

2



06 OCT 1966
SHELL STRESS DISTRIBUTION
NET STRESSES - KSI
MERIDIONAL STATION - IN.
NOS
NIS
OOS
CIS
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
2.00


1966
THRUST CHAMBER, INJECTOR BOSS REGION
SHELL = 2, CASE = 1, CONFIG = 1
MERIDIONAL STRESS (INSIDE) MIS
MERIDIONAL STRESS (OUTSIDE) MOS
CIRCUMFERENTIAL STRESS (INSIDE) CIS
CIRCUMFERENTIAL STRESS (OUTSIDE) COS
MOS
MIS
COS
CIS
1.40 1.60 1.80 2.00 2.20 2.40 2.60 2.80
NAL STATION - IN.

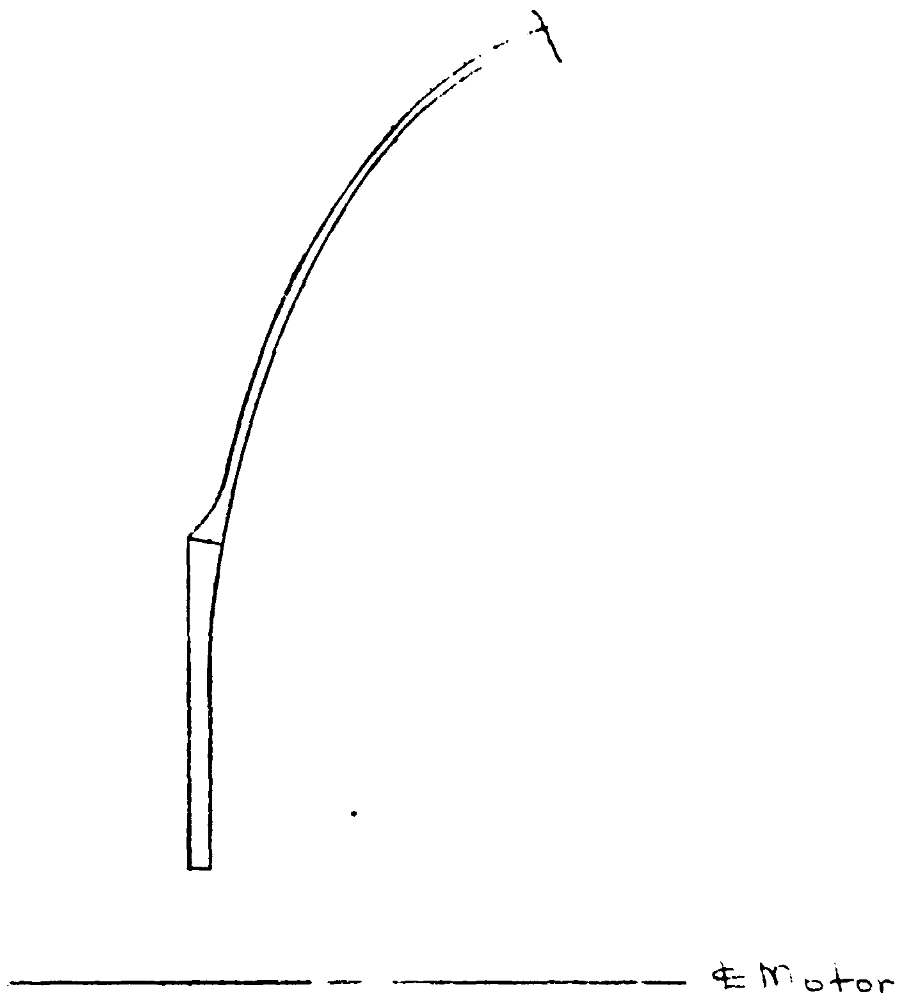


FIGURE 5

INJECTOR BOSS REGION (NO BOSS)

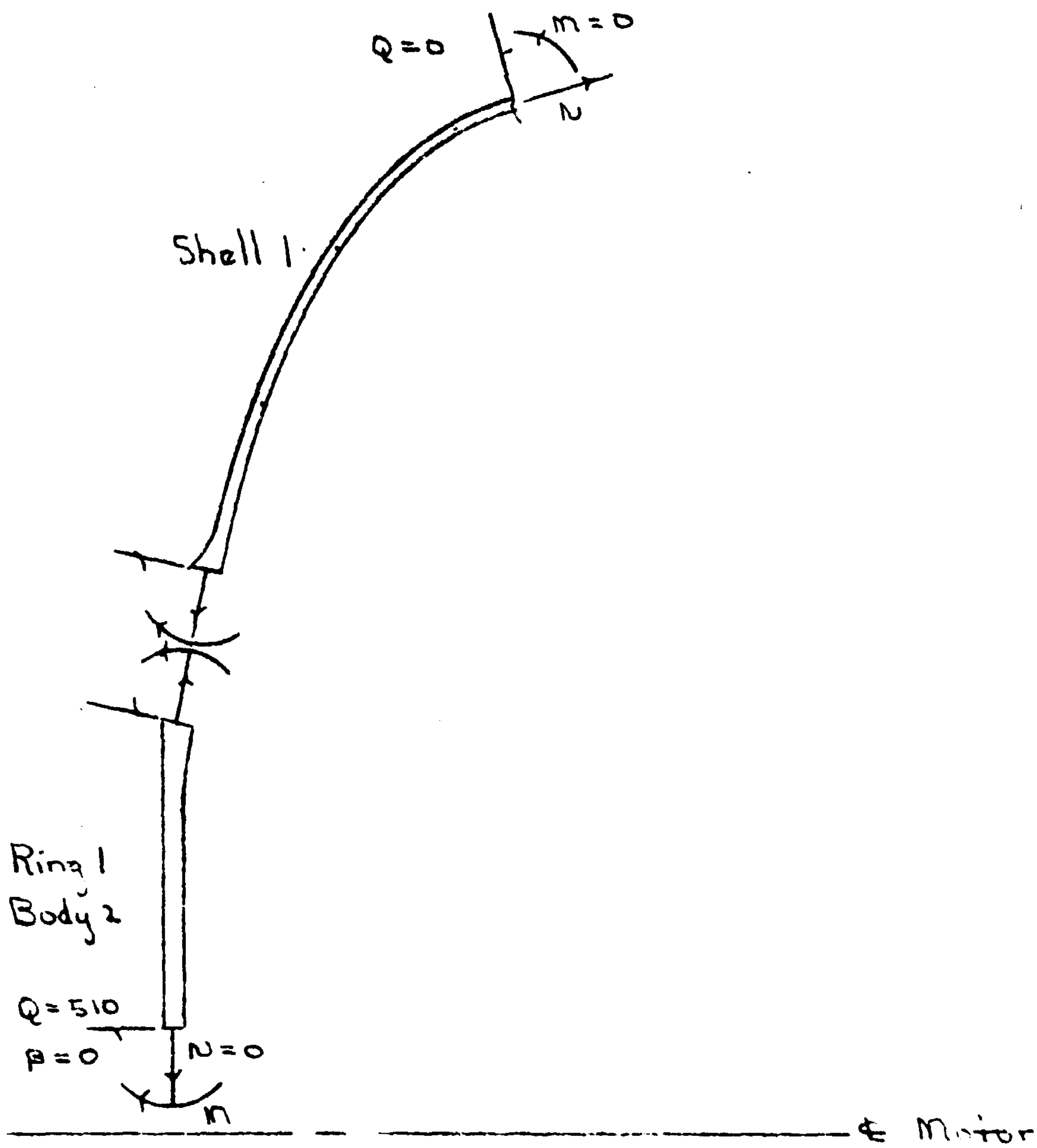


FIG. 6: INJECTOR BOSS REGION (NO BOSS)

10 IN HYBRID, COMBUSTION CHAMBER, INJECTOR BOSS REGION (NO E[illegible]) 6 OCT. 66

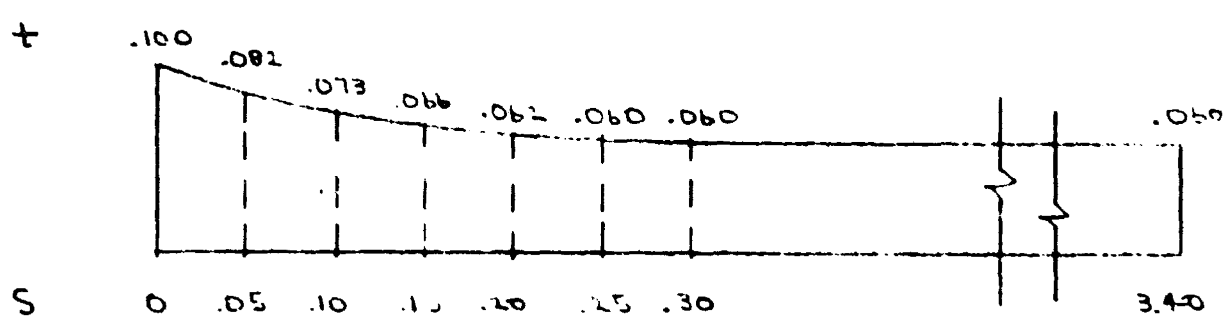
Ring 1, Body 2

$$\begin{cases} RLI = .56 \\ PHILI = 1.0 \\ XLI = 0 \end{cases} \qquad \begin{cases} RLO = 0 \\ PHILO = 0 \\ XLO = 0 \end{cases}$$

$$\begin{cases} RRI = 0 \\ PHIRRI = 0 \\ XRI = 0 \end{cases} \qquad \begin{cases} RRO = 2.34 \\ PHIRO = 13.5278 \\ XRO = .050 \end{cases}$$

$$\begin{cases} R_{CG} = 1.450 \\ A = 1.78(.10) = .178 \text{ IN}^2 \\ I_{yy} = \frac{1.78}{12}(.10)^3 = .0001483 \text{ IN}^4 \\ E = 2.65 \times 10^7 \text{ PSI} \end{cases}$$

Shell 1



NJ, 1,

NJ Sets, 2,1,

Location, 3,0,

No. of B.C., 5,

Body No., 1,1, 2,2,2,

Location, 1,1, 0,0,0,

B.C. No., 3,4, 2,4,5

Value, 0,0, 0,510,0,

$$\begin{cases} N_2 = 0 \\ Q_2 = .56\,p = .56(910) = 510 \text{ LB} \\ \beta = 0 \end{cases}$$

Shell 1 Closure Dome (Elliptical)

$a = 4.950$

$b = 2.220$

$x_1 = 2.34$

$$\tan\phi = \frac{b}{a}\frac{x}{\sqrt{a^2-x^2}}$$

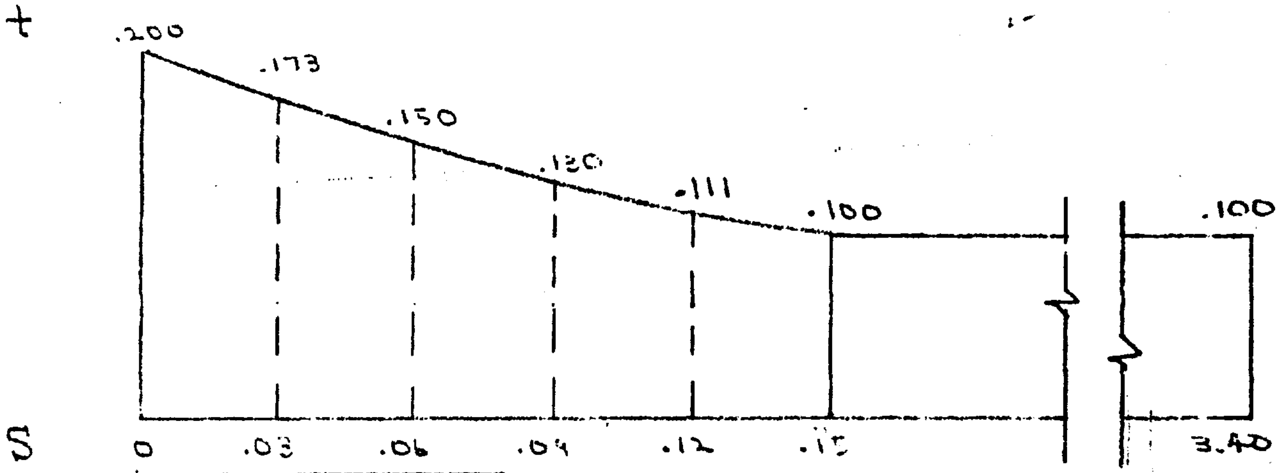
$$\tan\phi = \frac{2.220}{4.950}\frac{2.34}{\sqrt{(4.95)^2-(2.34)^2}} = \frac{1.0495}{\sqrt{19.027}}$$

$24.503 \quad 5.476$

$$\tan\phi = \frac{1.0495}{4.36} = .24071$$

$$\phi = 13^\circ\, 32' = 13.5333^\circ$$

Shell 1 Closure Dome (Elliptical)



S	t
0	.200
.03	.173
.06	.150
.09	.130
.12	.111
.15	.100
3.40	.100

United Technology Center DIVISION OF UNITED AIRCRAFT CORPORATION

PREPARED BY R W Bush DATE 9-[illegible]-66

REVIEWED BY DATE

INPUT VALUES FOR UNIT ANALYSIS
OF AN AXISYMMETRIC THIN SHELL PROJ. NO. ________

SHELL LENGTH 3.400 . POISSON'S RATIO 0.3 .

YOUNGS MODULUS 2.65×10^7 . NO. TAYLOR SERIES 5 . NO. SEGMENTS 50 .

MERIDIONAL STATION	R_1	R_2	THICKNESS	PHI
0	8.2177	10.0036		13.5278
.10	7.9920	9.9112		14.2342
.20	7.7602	9.8144		14.9611
.30	7.5526	9.7132		15.7104
.40	7.2797	9.6075		16.4[illegible]
.50	7.0319	9.4972		17.2839
.60	6.7797	9.3823		18.11[illegible]
.70	6.5231	9.2627		18.[illegible]
.80	6.2644	9.1383		19.8687
.90	6.0023	9.0090		20.6021
1.00	5.7381	8.8748		21.7772
1.10	5.4722	8.7356		22.7[illegible]
1.20	5.2057	8.[illegible]14		23.[illegible]
1.30	4.9389	8.4421		24.[illegible]787
1.40	4.6727	8.2876		26.[illegible]
1.50	4.4078	8.1[illegible]		27.4[illegible]01
1.60	4.1451	7.9631		28.78[illegible]4
1.70	3.8854	7.7932		30.[illegible]
1.80	3.6[illegible]6	7.6183		31.7[illegible]66
1.90	3.3787	7.4385		33.36[illegible]7
2.00	3.1326	7.2542		35.1[illegible]71
2.10	2.8955	7.0656		37.0[illegible]
2.20	2.6655	6.8733		3[illegible].0834
2.30	2.4446	6.6780		41.[illegible]31
2.40	2.2343	6.4806		43.[illegible]693
2.50	2.0[illegible]26	6.2826		46.[illegible]
2.60	1.8501	6.0856		49.2960
2.70	1.6790	5.8911		5[illegible].[illegible]401
2.80	1.52[illegible]8	5.7045		56.[illegible]
2.90	1.3860	5.5270		60.1511
3.00	1.2669	5.3640		64.4[illegible]11
3.10	1.1680	5.2206		69.1[illegible]
3.20	1.0905	5.1024		74.[illegible]
3.30	1.0355	[illegible].0157		79.64[illegible]
3.40	1.0058	4.9635		[illegible]

N-225 (5/63)

10 IN HYBRID,COMBUSTION CHAMBER,AFT,C02219,ELLIPSE PROPS, 27 SEPT. 66

INPUT DATA

A = 4.95000 B = 2.22000 X = 2.34000 DELTAS = 0.05000

GEOMETRIC PROPERTIES - ELLIPSOID OF REVOLUTION

NDELTAS	R1	R2	PHI
0.00000000	8.21771377E+00	1.00035762E+01	13.52775383
0.05000000	8.10567348E+00	9.95790512E+00	13.87851701
0.10000000	7.99203937E+00	9.91115239E+00	14.23419102
0.15000000	7.87686136E+00	9.86330999E+00	14.59498674
0.20000000	7.76019071E+00	9.81436971E+00	14.96112497
0.25000000	7.64208010E+00	9.76432315E+00	15.33283717
0.30000000	7.52258361E+00	9.71316180E+00	15.71036609
0.35000000	7.40175677E+00	9.66087698E+00	16.09396658
0.40000000	7.27965660E+00	9.60745989E+00	16.48390636
0.45000000	7.15634163E+00	9.55290159E+00	16.88046695
0.50000000	7.03187192E+00	9.49719306E+00	17.28394454
0.55000000	6.90630912E+00	9.44032516E+00	17.69465108
0.60000000	6.77971648E+00	9.38228872E+00	18.11291535
0.65000000	6.65215891E+00	9.32307449E+00	18.53908417
0.70000000	6.52370299E+00	9.26267321E+00	18.97352366
0.75000000	6.39441705E+00	9.20107565E+00	19.41662065
0.80000000	6.26437117E+00	9.138[illegible]7261E+00	19.86878421
0.85000000	6.13363724E+00	9.07425497E+00	20.33044728
0.90000000	6.00228904E+00	9.00901377E+00	20.80206842
0.95000000	5.87040222E+00	8.94254022E+00	21.28413377
1.00000000	5.73805440E+00	8.87482578E+00	21.77715916
1.05000000	5.60532522E+00	8.80586225E+00	22.28169232
1.10000000	5.47229635E+00	8.73564181E+00	22.79831544
1.15000000	5.33905160E+00	8.66415717E+00	23.32764750
1.20000000	5.20567696E+00	8.59140160E+00	23.87034870
1.25000000	5.07226065E+00	8.51736914E+00	24.42712070
1.30000000	4.93889318E+00	8.44205467E+00	24.99871301
1.35000000	4.80566744E+00	8.36545409E+00	25.58592529
1.40000000	4.67267875E+00	8.28756454E+00	26.18961176
1.45000000	4.54002494E+00	8.20838456E+00	26.81068565
1.50000000	4.40780640E+00	8.12791436E+00	27.45012401
1.55000000	4.27612619E+00	8.04615609E+00	28.10897300
1.60000000	4.14509009E+00	7.96311413E+00	28.78835355
1.65000000	4.01480670E+00	7.87879552E+00	29.48946756
1.70000000	3.88538751E+00	7.79321029E+00	30.21360451
1.75000000	3.75694696E+00	7.70637202E+00	30.96214863
1.80000000	3.62960258E+00	7.61829831E+00	31.73658659
1.85000000	3.50347502E+00	7.52901145E+00	32.53851567
1.90000000	3.37868815E+00	7.43853913E+00	33.36965250
1.95000000	3.25536914E+00	7.34691525E+00	34.23184214
2.00000000	3.13364857E+00	7.25418086E+00	35.12706770
2.05000000	3.01366045E+00	7.16038524E+00	36.05746011
2.10000000	2.89554232E+00	7.06558710E+00	37.02530804
2.15000000	2.77943531E+00	6.96985601E+00	38.03306768
2.20000000	2.66548418E+00	6.87327392E+00	39.08337203
2.25000000	2.55383736E+00	6.77593702E+00	40.17903916
2.30000000	2.44464695E+00	6.67795772E+00	41.32307901
2.35000000	2.33806874E+00	6.57946691E+00	42.51869759
2.40000000	2.23426212E+00	6.48061652E+00	43.76929777
2.45000000	2.13339008E+00	6.38158227E+00	45.07847508

2.50000000	2.03561899D+00	6.28256678D+00	46.45000679
2.55000000	1.94111851D+00	6.18380281D+00	47.88783208
2.60000000	1.85006127D+00	6.08555679D+00	49.39602058
2.65000000	1.76262260D+00	5.98813240D+00	50.97872609
2.70000000	1.67898007D+00	5.89187416D+00	52.64012183
2.75000000	1.59931295D+00	5.79717086D+00	54.38431311
2.80000000	1.52380155D+00	5.70445843D+00	56.21522331
2.85000000	1.45262640D+00	5.61422215D+00	58.13644915
2.90000000	1.38596726D+00	5.52699756D+00	60.15108242
2.95000000	1.32400194D+00	5.44336959D+00	62.26149691
3.00000000	1.26690491D+00	5.36396936D+00	64.46910259
3.05000000	1.21484574D+00	5.28946800D+00	66.77407363
3.10000000	1.16798732D+00	5.22056681D+00	69.17506269
3.15000000	1.12648381D+00	5.15798333D+00	71.66892128
3.20000000	1.09047860D+00	5.10243324D+00	74.25045324
3.25000000	1.06010193D+00	5.05460812D+00	76.91223437
3.30000000	1.03546870D+00	5.01515016D+00	79.64453428
3.35000000	1.01667613D+00	4.98462500D+00	82.43537339
3.40000000	1.00380172D+00	4.96349506D+00	85.27073826

######## [redacted] ##

10 IN HYBRID,COMBUSTION CHAMBER,INJECTOR BOSS REGION (NO BOSS) 6 OCT. 66

SHELL #1 CLUSURE DOME (ELLIPTICAL)

SHELL UNIT ANALYSIS

SHELL NO. 1, CONFIGURATION NO. 1

INPUT IS:

TAYLORS SERIES FXPANSIONS OF 5 TERMS ARE USED TO SOLVE THE DIFFERENTIAL EQUATIONS SIMULTANEOUSLY.

THE 3.4000 INCH LONG SHELL SECTION IS DIVIDED INTO 50 SEGMENTS EACH OF WHICH IS 0.0680 INCHES LONG.

MODULUS OF ELASTICITY, E = 2.65000P+07

POISSON S RATIO, MU = 0.3000

MERIDIONALLY VARING PARAMFTER FUNCTIONS:

RADIUS 1 =	8.2177P+00	7.9920P+00	7.7602P+00	7.5526P+00	7.2797P+00	7.0319P+00	6.7797P+00
S =	0.0000P+00	1.0000P-01	2.0000P-01	3.0000P-01	4.0000P-01	5.0000P-01	6.0000P-01
	6.5237P+00	6.2644P+00	6.0023P+00	5.7381P+00	5.4723P+00	5.2057P+00	4.9389P+00
	7.0000P-01	8.0000P-01	9.0000P-01	1.0000P+00	1.1000P+00	1.2000P+00	1.3000P+00
	4.6727P+00	4.4078P+00	4.1451P+00	3.8854P+00	3.6296P+00	3.3787P+00	3.1336P+00
	1.4000P+00	1.5000P+00	1.6000P+00	1.7000P+00	1.8000P+00	1.9000P+00	2.0000P+00
	2.8955P+00	2.6655P+00	2.4446P+00	2.2343P+00	2.0356P+00	1.8501P+00	1.6790P+00
	2.1000P+00	2.2000P+00	2.3000P+00	2.4000P+00	2.5000P+00	2.6000P+00	2.7000P+00
	1.5238P+00	1.3860P+00	1.2669P+00	1.1680P+00	1.0905P+00	1.0355P+00	1.0038P+00
	2.8000P+00	2.9000P+00	3.0000P+00	3.1000P+00	3.2000P+00	3.3000P+00	3.4000P+00
RADIUS 2 =	1.0004P+01	9.9112P+00	9.8144P+00	9.7132P+00	9.6075P+00	9.4972P+00	9.3823P+00
S =	0.0000P+00	1.0000P-01	2.0000P-01	3.0000P-01	4.0000P-01	5.0000P-01	6.0000P-01
	9.2627P+00	9.1383P+00	9.0090P+00	8.8748P+00	8.7356P+00	8.5914P+00	8.4421P+00
	7.0000P-01	8.0000P-01	9.0000P-01	1.0000P+00	1.1000P+00	1.2000P+00	1.3000P+00
	8.2876P+00	8.1279P+00	7.9631P+00	7.7932P+00	7.6183P+00	7.4385P+00	7.2542P+00
	1.4000P+00	1.5000P+00	1.6000P+00	1.7000P+00	1.8000P+00	1.9000P+00	2.0000P+00
	7.0656P+00	6.8733P+00	6.6780P+00	6.4806P+00	6.2826P+00	6.0856P+00	5.8919P+00
	2.1000P+00	2.2000P+00	2.3000P+00	2.4000P+00	2.5000P+00	2.6000P+00	2.7000P+00
	5.7045P+00	5.5270P+00	5.3640P+00	5.2206P+00	5.1024P+00	5.0152P+00	4.9635P+00
	2.8000P+00	2.9000P+00	3.0000P+00	3.1000P+00	3.2000P+00	3.3000P+00	3.4000P+00

THICKNFSS =	1.0000P-01	8.2000P-02	7.3000P-02	6.6000P-02	6.2080P-02	6.0000P-02	6.0000P-02
S =	0.0000P+0	5.0000P-02	1.0000P-01	1.5000P-01	2.0000P-01	2.5000P-01	3.4000P+00
PHI =	1.3528P+01	1.4234P+01	1.4961P+01	1.5710P+01	1.6484P+01	1.7284P+01	1.8113P+01
S =	0.0000P+00	1.0000P-01	2.0000P-01	3.0000P-01	4.0000P-01	5.0000P-01	6.0000P-01
	1.8973P+01	1.9869P+01	2.0802P+01	2.1777P+01	2.2798P+01	2.3870P+01	2.4999P+01
	7.0000P-01	8.0000P-01	9.0000P-01	1.0000P+00	1.1000P+00	1.2000P+00	1.3000P+00
	2.6190P+01	2.7450P+01	2.8788P+01	3.0214P+01	3.1737P+01	3.3370P+01	3.5127P+01
	1.4000P+00	1.5000P+00	1.6000P+00	1.7000P+00	1.8000P+00	1.9000P+00	2.0000P+00
	3.7025P+01	3.9083P+01	4.1323P+01	4.3769P+01	4.6450P+01	4.9396P+01	5.2640P+01
	2.1000P+00	2.2000P+00	2.3000P+00	2.4000P+00	2.5000P+00	2.6000P+00	2.7000P+00
	5.6215P+01	6.0151P+01	6.4469P+01	5.9175P+01	7.4251P+01	7.9645P+01	8.5271P+01
	2.8000P+00	2.9000P+00	3.0000P+00	3.1000P+00	3.2000P+00	3.3000P+00	3.4000P+00

RING 1, BODY 2

RING UNIT ANALYSIS

RING NO. 1, CONFIGURATION NO. 1

INPUT IS:

	RADIUS, IN.	PHI, DEG.	X, IN.
LI	0.560	1.000	0.000
LO	0.000	0.000	0.000
RI	0.000	0.000	0.000
RO	2.340	13.528	0.050

RCG = 1.450 A = 0.178 IYY = 0.000 E = 2.6500E+07

OUTPUT IS:

	QNET	MNET	AXIAL EQUIL
M-LI	0.0000E+00	-3.8621E-01	0.0000E+00
Q-	6.7402E-03	-3.4367E-01	5.5991E-01
N-	-3.8615E-01	-5.9988E-03	9.7733E-03
M-LO	0.0000E+00	0.0000E+00	0.0000E+00
Q-	0.0000E+00	0.0000E+00	0.0000E+00
N-	0.0000E+00	0.0000E+00	0.0000E+00
M-RI	0.0000E+00	0.0000E+00	0.0000E+00
Q-	0.0000E+00	0.0000E+00	0.0000E+00
N-	0.0000E+00	0.0000E+00	0.0000E+00
M-RO	0.0000E+00	1.6138E+00	0.0000E+00
Q-	-3.7749E-01	-1.4153E+00	-2.2751E+00
N-	1.5690E+00	-2.5752E-01	-5.4737E-01
FX	0.0000E+00	0.0000E+00	1.4500E+00
FY	1.0000E+00	0.0000E+00	0.0000E+00
MCG	0.0000E+00	1.0000E+00	0.0000E+00

DEL-CG = 8.4573E-07 x Q-NET BETA-CG = 5.3499E-04 x M-NET

SHELL/RING BOUNDARY CONDITIONS AND FORCES

CASE NO. 1, CONFIGURATION NO. 1

SHELL NO. 1

M-R = 0.0000D+00

Q-R = 0.0000D+00

PRESSURE = 9.1000D+02

RING NO. 1

RET-LI = 0.0000D+00

W-LI = 5.1000D+02

N-LI = 0.0000D+00

FX = 1.6200D+03 FY = 0.0000D+00 MCG = 0.0000D+00

SHELL/RING DISCONTINUITY DEFORMATION AND FORCE SOLUTIONS

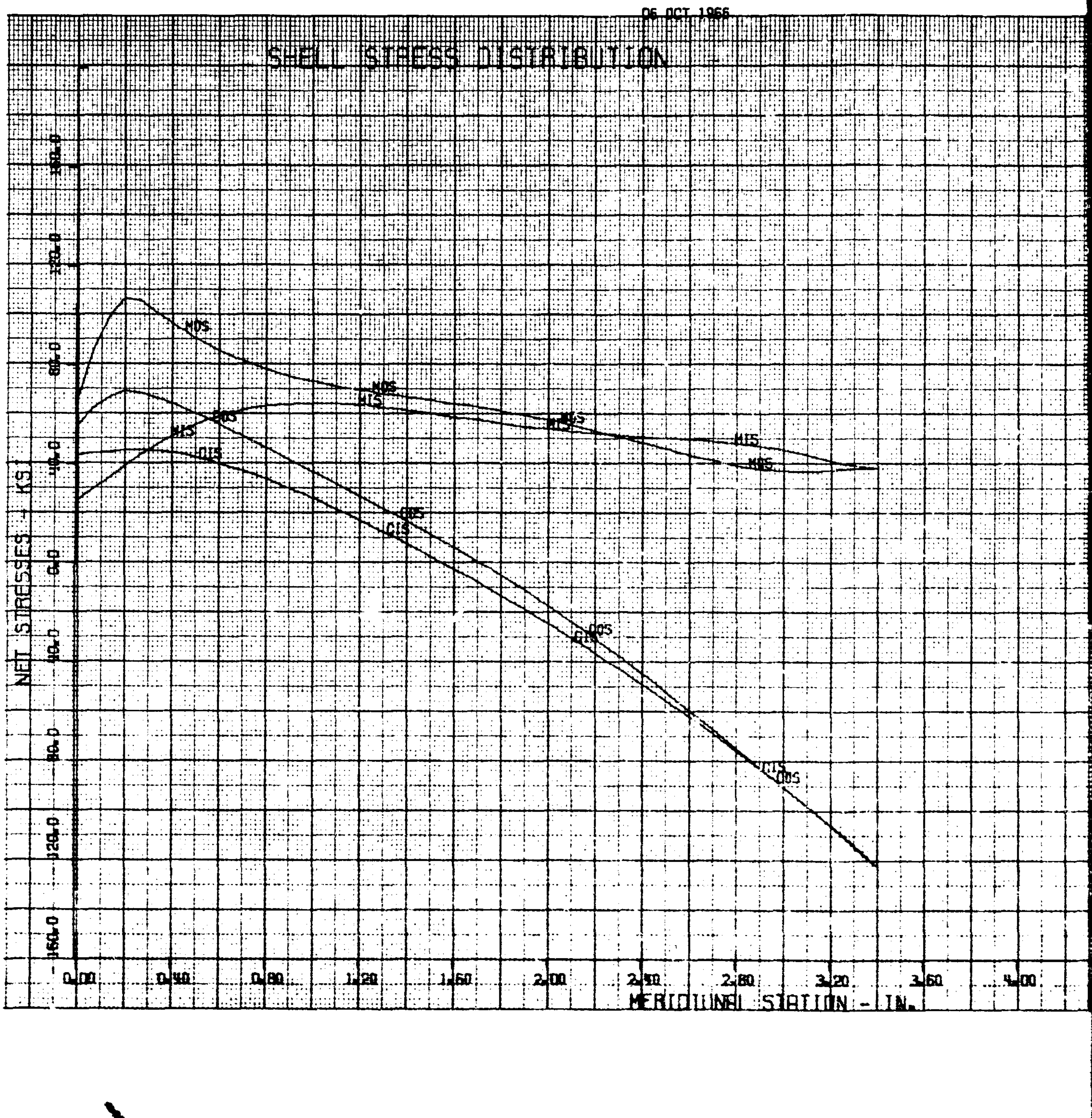
CASE NO. 1, CONFIGURATION NO. 1

SHELL NO. 1	LEFT END	RIGHT END
DELTA	3.183585P-03	-2.495461P-02
BETA	2.523848P-11	-1.676157P-02
M	-3.326045P+01	0.000000P+00
Q	5.985496P+01	0.000000P+00
N	4.564371P+03	2.286858P+03

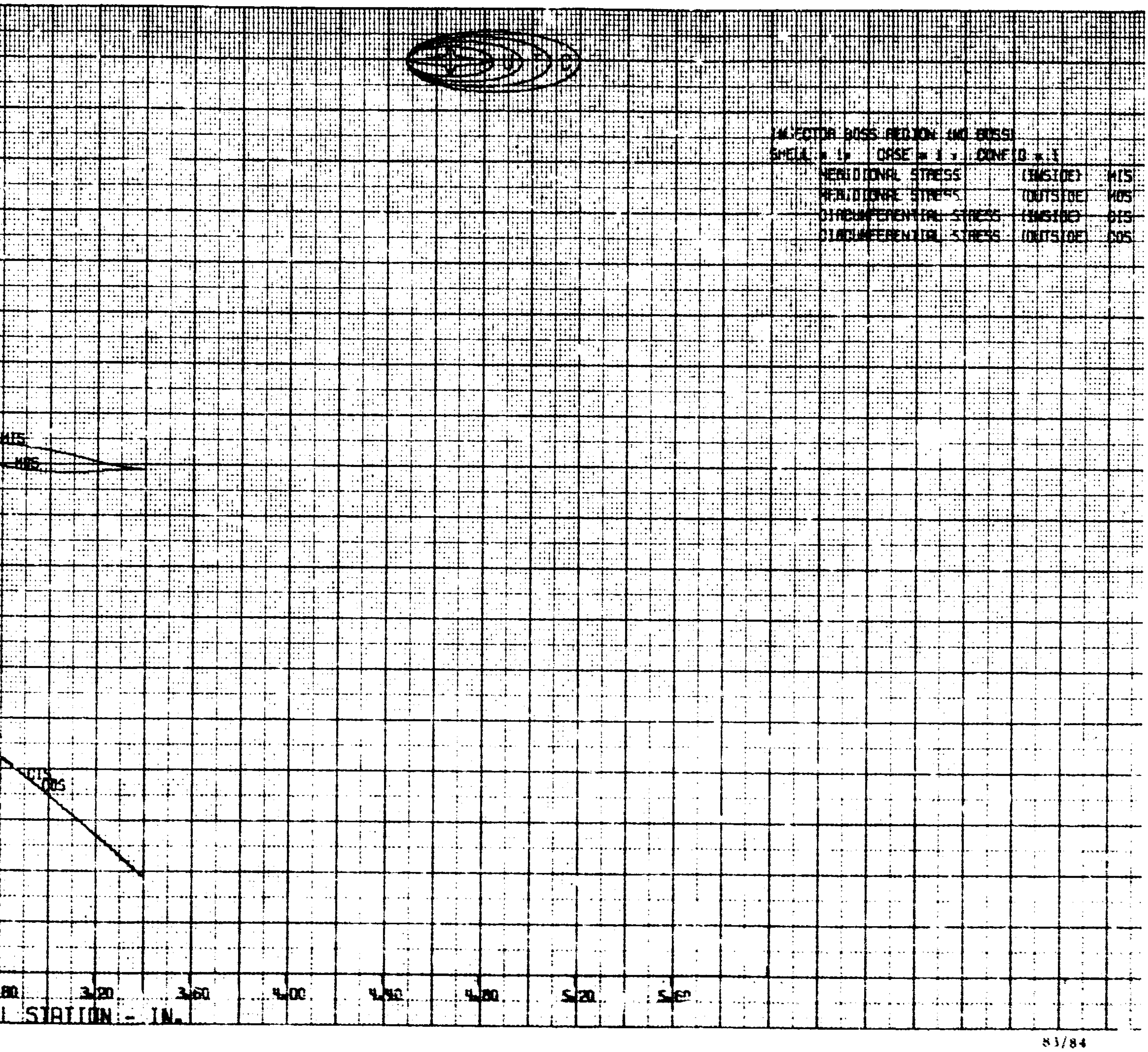
RING NO. 1	LEFT INSIDE	LEFT OUTSIDE	RIGHT INSIDE	RIGHT OUTSIDE
DELTA	3.183585P-03	0.000000P+00	0.000000P+00	3.183585P-03
BETA	0.000000P+00	0.000000P+00	0.000000P+00	0.000000P+00
M	-3.855630P+03	0.000000P+00	0.000000P+00	-3.326045P+01
Q	5.100000P+02	0.000000P+00	0.000000P+00	5.98549[illegible]
N	0.000000P+00	0.000000P+00	0.000000P+00	4.564371P+03

DEL-CG = 3.183585P-03   BETA-CG = 0.000000P+00

M-NET = 0.000000P+00   Q-NET = 7.142435P+03



06 OCT 1966
SHELL STRESS DISTRIBUTION
NET STRESSES - KSI
MERIDIONAL STATION - IN.
MOS
MIS
OOS
OIS



INJECTOR BOSS REGION (NO BOSS)
SHELL = 1, CASE = 1, CONFIG = 1
MERIDIONAL STRESS (INSIDE) MIS
MERIDIONAL STRESS (OUTSIDE) MOS
CIRCUMFERENTIAL STRESS (INSIDE) CIS
CIRCUMFERENTIAL STRESS (OUTSIDE) COS
MIS
MOS
CIS
COS
3.20
3.60
4.00
4.40
4.80
5.20
5.60
STATION - IN.

83/84

2

Ref. — Convair (Astronautics) Division
General Dynamics Corp., Structures
Technical Memorandum No. 5

$M = 69,600$ in-lb (Limit) $= 104,400$ in-lb (Ult)
Aft Launch Fin
Captive Flight

$L = 48.75$ in $\quad L/R = 48.75/5.020 = 9.711$

$R = 5.020$ in $\quad R/t = 5.020/.040 = 125.5$

$t = .040$ in

$$f_b = \frac{M}{\pi R^2 t} = \frac{104,400}{\pi(5.020)^2(.040)} = 34,042 \text{ psi}$$

Pure Bending of Unpressurized Unstiffened Circular Cylinder, Clamped Ends (Page 7)

$$\frac{F_{cr}}{E} \times 10^3 = 1.35$$

$$F_{cr} = \frac{26.5 \times 10^6 (1.35)}{10^3} = 35,775 \text{ psi}$$

$$MS = \frac{F_{cr}}{f_b} - 1 = \frac{\overset{1.05}{35,775}}{34,042} - 1 = \underline{\underline{.05}}$$

NOTE: SINCE THE GRAIN WILL BE IN PLACE AND BEARING ON THE CASE UNDER EXTERNAL LOADS THIS ANALYSIS IS HIGHLY CONSERVATIVE.

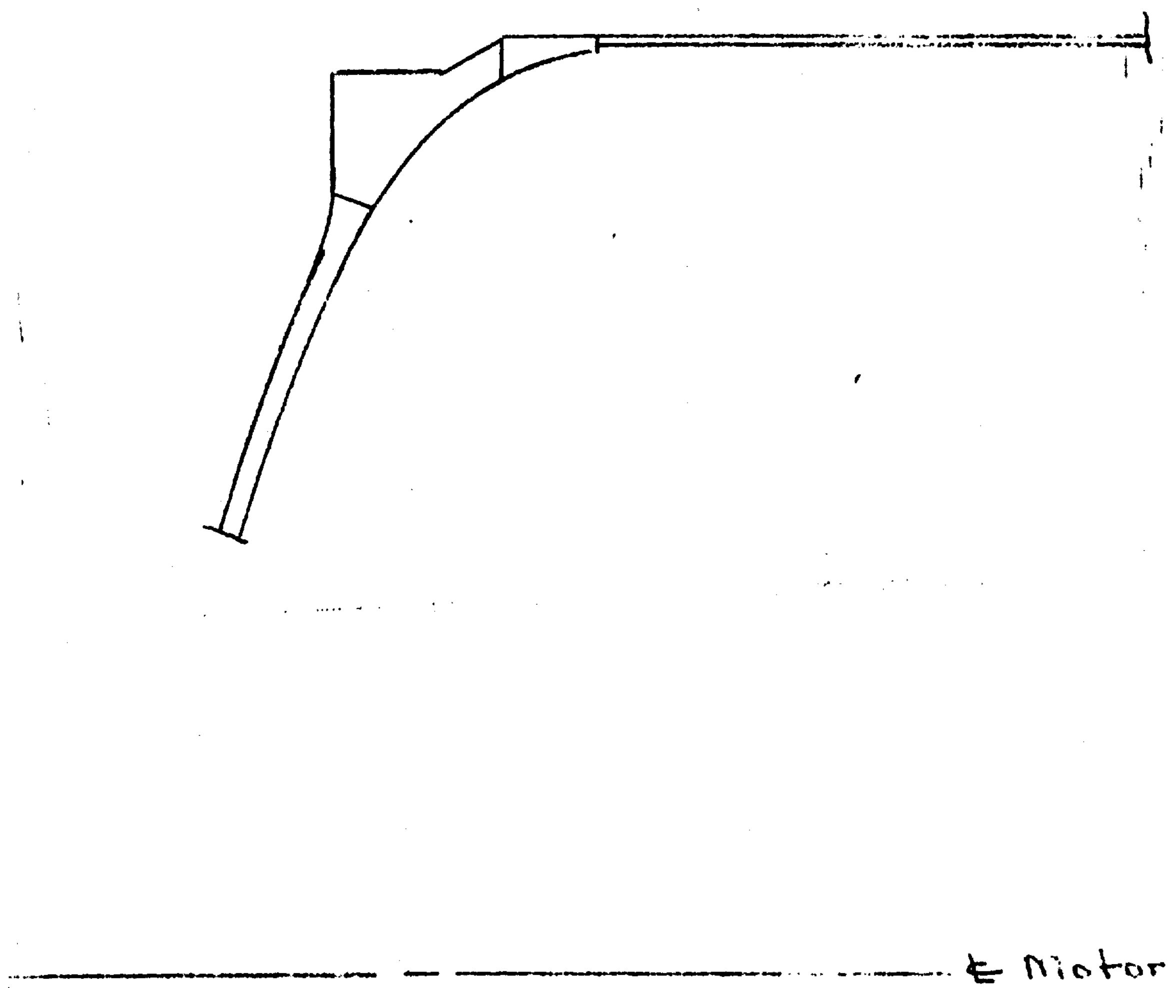


FIGURE 7
FWD CLOSURE, Y RING REGION

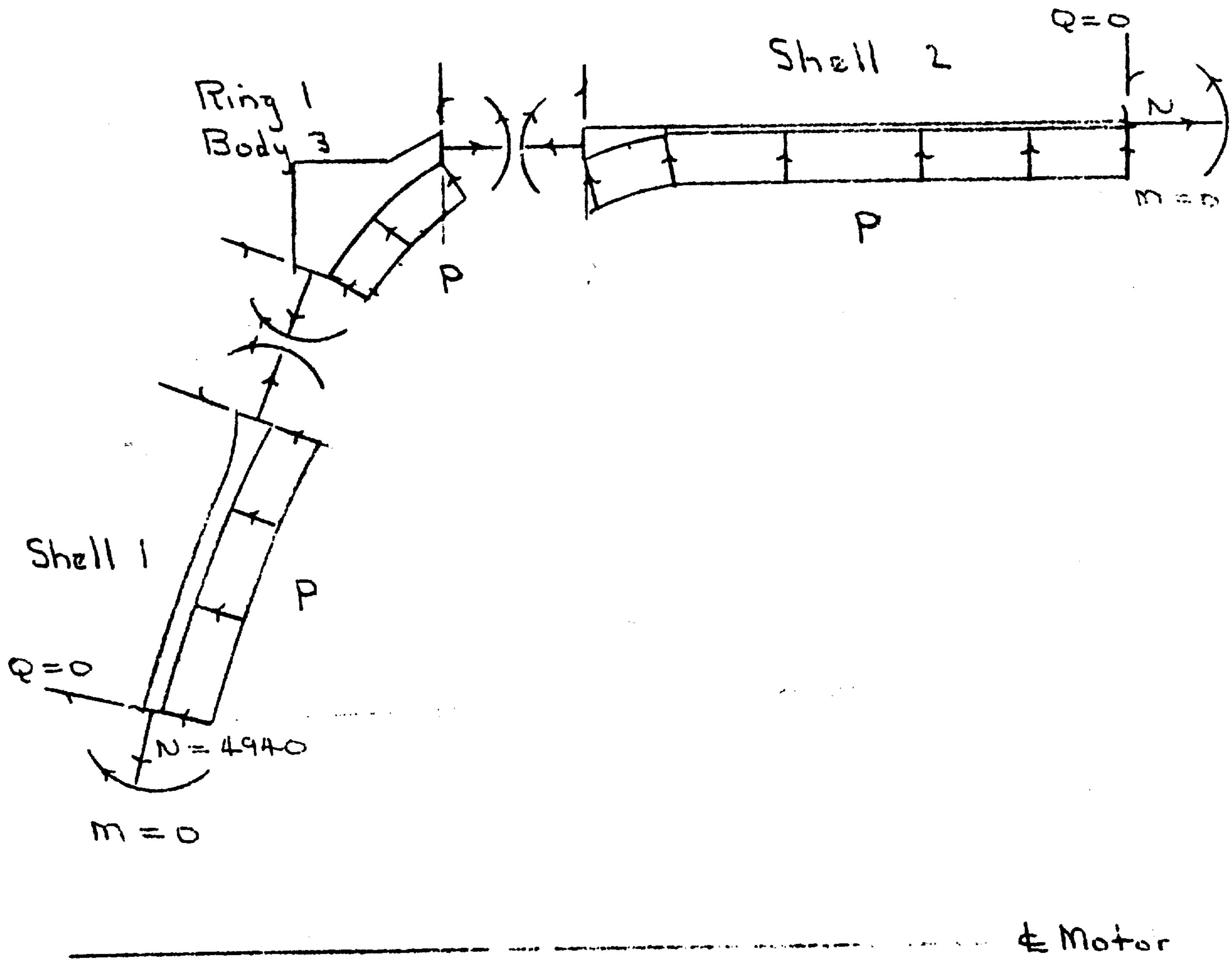
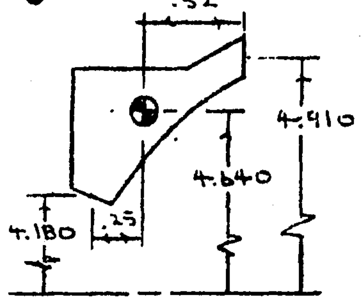
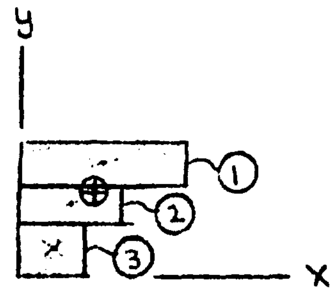


FIGURE 8

FWD CLOSURE, Y RING REGION

Ring 1, Body 3





$A = .2400 + .1007 + .0700 = .4107 \text{ IN}^2$

$Ay = .13920 + .03625 + .00980 = .18525 \text{ IN}^3$

$Ax = .12000 + .02669 + .00875 = .15544 \text{ IN}^3$

$Ax^2 = .06000 + .00707 + .00109 = .06816 \text{ IN}^4$

$I_{oy} = .02000 + .00236 + .00036 = .02272 \text{ IN}^4$

$\bar{x} = .15544 / .4107 = .3785 \text{ IN}$

$\bar{y} = .18525 / .4107 = .4511 \text{ IN}$

$I_{yy} = .06816 + .02272 - .4107(.3785)^2 = .03204 \text{ IN}^4$

.05884

$F_x = .67(910) = 610 \text{ LB}$

$F_y = .67(910) = 610 \text{ LB}$

$M_{CG} = .947(910)0 = 0$

$$\begin{cases} RLI = 4.180 \\ PHILI = 35.26180 \\ XLI = .25 \end{cases} \qquad \begin{cases} RLO = 0 \\ PHILO = 0 \\ XLO = 0 \end{cases}$$

$$\begin{cases} RRI = 0 \\ PHIRI = 0 \\ XRI = 0 \end{cases} \qquad \begin{cases} RRO = 4.940 \\ PHIRO = 90 \\ XRO = .52 \end{cases}$$

$$\begin{cases} R_{CG} = 4.640 \\ A = .4107 \\ I_{yy} = .03204 \\ E = 26.5 \times 10^6 \end{cases}$$

STRUCTURAL ANALYSIS OF MULTIPLE SHELL/RING STRUCTURES   UNITED TECHNOLOGY CENTER   29 SEPT 1966

COMBUSTION CHAMBER, [redacted], 10 IN HYBRID   C02219   R.D.BUSH

SHELL #1 CLOSURE DOME (ELLIPTICAL)

SHELL UNIT ANALYSIS

SHELL NO. 1, CONFIGURATION NO. 1

INPUT 1ST

TAYLORS SERIES EXPANSIONS OF 5 TERMS ARE USED TO SOLVE THE DIFFERENTIAL EQUATIONS SIMULTANEOUSLY.

THE 3.3679 INCH LONG SHELL SECTION IS DIVIDED INTO 50 SEGMENTS EACH OF WHICH IS 0.0674 INCHES LONG.

MODULUS OF ELASTICITY, E = 2.65000E+07

POISSON S RATIO, MU = 0.3000

MERIDIONALLY VARING PARAMETER FUNCTIONS:

RADIUS 1 =	1.0503E+01	1.0393E+01	1.0272E+01	1.0142E+01	1.0002E+01	9.8532E+00	9.6949E+00
S =	0.0000E+00	1.0000E-01	2.0000E-01	3.0000E-01	4.0000E-01	5.0000E-01	6.0000E-01
	9.5276E+00	9.3517E+00	9.1674E+00	8.9749E+00	8.7747E+00	8.5669E+00	8.3520E+00
	7.0000E-01	8.0000E-01	9.0000E-01	1.0000E+00	1.1000E+00	1.2000E+00	1.3000E+00
	8.1303E+00	7.9021E+00	7.6680E+00	7.4282E+00	7.1833E+00	6.9338E+00	6.6801E+00
	1.4000E+00	1.5000E+00	1.6000E+00	1.7000E+00	1.8000E+00	1.9000E+00	2.0000E+00
	6.4227E+00	6.1622E+00	5.8992E+00	5.6343E+00	6.3681E+00	5.1014E+00	4.8347E+00
	2.1000E+00	2.2000E+00	2.3000E+00	2.4000E+00	2.5000E+00	2.6000E+00	2.7000E+00
	4.5689E+00	4.3048E+00	4.0432E+00	3.7849E+00	3.5309E+00	3.2821E+00	3.1601E+00
	2.8000E+00	2.9000E+00	3.0000E+00	3.1000E+00	3.2000E+00	3.3000E+00	3.3500E+00
	3.1159E+00						
	3.3679E+00						

RADIUS 2 =	1.0856E+01	1.0818E+01	1.0776E+01	1.0730E+01	1.0681E+01	1.0627E+01	1.0570E+01
S =	0.0000E+00	1.0000E-01	2.0000E-01	3.0000E-01	4.0000E-01	5.0000E-01	6.0000E-01
	1.0509E+01	1.0444E+01	1.0375E+01	1.0302E+01	1.0225E+01	1.0143E+01	1.0058E+01
	7.0000E-01	8.0000E-01	9.0000E-01	1.0000E+00	1.1000E+00	1.2000E+00	1.3000E+00
	9.9680E+00	9.8738E+00	9.7753E+00	9.6724E+00	9.5649E+00	9.4528E+00	9.3361E+00
	1.4000E+00	1.5000E+00	1.6000E+00	1.7000E+00	1.8000E+00	1.9000E+00	2.0000E+00
	9.2146E+00	9.0883E+00	8.9571E+00	8.8210E+00	8.6799E+00	8.5336E+00	8.3823E+00
	2.1000E+00	2.2000E+00	2.3000E+00	2.4000E+00	2.5000E+00	2.6000E+00	2.7000E+00

	8.2250E+00	8.0641E+00	7.8973E+00	7.7254E+00	7.5486E+00	7.3670E+00	7.2745E+00
	2.8000E+00	2.9000E+00	3.0000E+00	3.1000E+00	3.2000E+00	3.3000E+00	3.3500E+00
	7.2404E+00						
	3.3679E+00						

THICKNESS =	1.0000E-01	1.0000E-01	1.0400E-01	1.3000E-01	1.7500E-01	2.0000E-01	2.0000E-01
S =	0.0000E+00	3.0000E+00	3.1000E+00	3.2000E+00	3.3000E+00	3.3500E+00	3.3679E+00

PHI =	5.2771E+00	5.8253E+00	6.3796E+00	6.9407E+00	7.5093E+00	8.0862E+00	8.6721E+00
S =	0.0000E+00	1.0000E-01	2.0000E-01	3.0000E-01	4.0000E-01	5.0000E-01	6.0000E-01
	9.2680E+00	9.8747E+00	1.0493E+01	1.1124E+01	1.1770E+01	1.2430E+01	1.3107E+01
	7.0000E-01	8.0000E-01	9.0000E-01	1.0000E+00	1.1000E+00	1.2000E+00	1.3000E+00
	1.3802E+01	1.4516E+01	1.5251E+01	1.6010E+01	1.6793E+01	1.7604E+01	1.8445E+01
	1.4000E+00	1.5000E+00	1.6000E+00	1.7000E+00	1.8000E+00	1.9000E+00	2.0000E+00
	1.9319E+01	2.0229E+01	2.1178E+01	2.2171E+01	2.3211E+01	2.4304E+01	2.5457E+01
	2.1000E+00	2.2000E+00	2.3000E+00	2.4000E+00	2.5000E+00	2.6000E+00	2.7000E+00
	2.6674E+01	2.7963E+01	2.9335E+01	3.0797E+01	3.2361E+01	3.4041E+01	3.4929E+01
	2.8000E+00	2.9000E+00	3.0000E+00	3.1000E+00	3.2000E+00	3.3000E+00	3.3500E+00
	3.5262E+01						
	3.3679E+00						

SHELL #2 CYLINDER WALL

SHELL UNIT ANALYSIS

SHELL NO. 2, CONFIGURATION NO. 1

INPUT IS:

TAYLORS SERIES EXPANSIONS OF 5 TERMS ARE USED TO SOLVE THE DIFFERENTIAL EQUATIONS SIMULTANEOUSLY.

THE 3.0000 INCH LONG SHELL SECTION IS DIVIDED INTO 50 SEGMENTS EACH OF WHICH IS 0.0600 INCHES LONG.

MODULUS OF ELASTICITY, E = 2.65000E+07

POISSON S RATIO, MU = 0.3000

MERIDIONALLY VARING PARAMETER FUNCTIONS:

```
     RADIUS 1 =    1.0000E+10  1.0000E+10
            S =    0.0000E+00  3.0000E+00

     RADIUS 2 =    4.9400E+00  4.9625E+00  4.9825E+00  5.0000E+00  5.0400E+00  5.0200E+00  5.0200E+00
            S =    0.0000E+00  1.0000E-01  2.0000E-01  3.0000E-01  4.0000E-01  5.0000E-01  5.4000E-01

                   5.0200E+00
                   3.0000E+00

    THICKNESS =    2.0000E-01  1.5500E-01  1.1500E-01  8.0000E-02  5.2000E-02  4.0000E-02  4.0000E-02
            S =    0.0000E+00  1.0000E-01  2.0000E-01  3.0000E-01  4.0000E-01  5.0000E-01  5.4000E-01

                   4.0000E-02
                   3.0000E+00

          PHI =    9.0000E+01  9.0000E+01
            S =    0.0000E+00  3.0000E+00
```

WING 1, BUOY 3

WING UNIT ANALYSIS

RING NO. 1, CONFIGURATION NO. 1

INPUT IS:

	RADIUS, IN.	PHI, DEG.	X, IN.
LI	4.180	35.262	0.250
LO	0.000	0.000	0.000
RI	0.000	0.000	0.000
RU	4.940	90.000	0.520

RCG = 4.640 A = 0.411 IYY = 0.032 E = 2.650E+07

OUTPUT IS:

	QNET	MNET	AXIAL EQUIL
M-LI	0.0000E+00	-9.0086E-01	0.0000E+00
Q-	5.2008E-01	-4.6838E-01	3.4131E+00
N-	-7.3557E-01	-5.5343E-02	2.4132E+00
M-LO	0.0000E+00	0.0000E+00	0.0000E+00
Q-	0.0000E+00	0.0000E+00	0.0000E+00
N-	0.0000E+00	0.0000E+00	0.0000E+00
M-RI	0.0000E+00	0.0000E+00	0.0000E+00
Q-	0.0000E+00	0.0000E+00	0.0000E+00
N-	0.0000E+00	0.0000E+00	0.0000E+00
M-RU	0.0000E+00	1.0647E+00	0.0000E+00
Q-	-1.0647E+00	-5.5362E-01	-8.8420E-09
N-	1.9056E-09	-3.1940E-01	-4.9400E+00
FX	0.0000E+00	0.0000E+00	4.6400E+00
FY	1.0000E+00	0.0000E+00	0.0000E+00
MCG	0.0000E+00	1.0000E+00	0.0000E+00

DELTA-CG = 1.9782E-06 x Q-NET BETA-CG = 2.5357E-05 x M-NET

SHELL/RING BOUNDARY CONDITIONS AND FORCES

CASE NO. 1, CONFIGURATION NO. 1

SHELL NO. 1

M-L = 0.0000E+00

Q-L = 0.0000E+00

N-L = 4.9400E+03

PRESSURE = 9.1000E+02

SHELL NO. 2

M-R = 0.0000E+00

Q-R = 0.0000E+00

PRESSURE = 9.1000E+02

RING NO. 1

FX = 6.1000E+02   FY = 6.1000E+02   MCG = 0.0000E+00

SHELL/RING DISCONTINUITY DEFORMATION AND FORCE SOLUTIONS CASE NO. 1, CONFIGURATION NO. 1

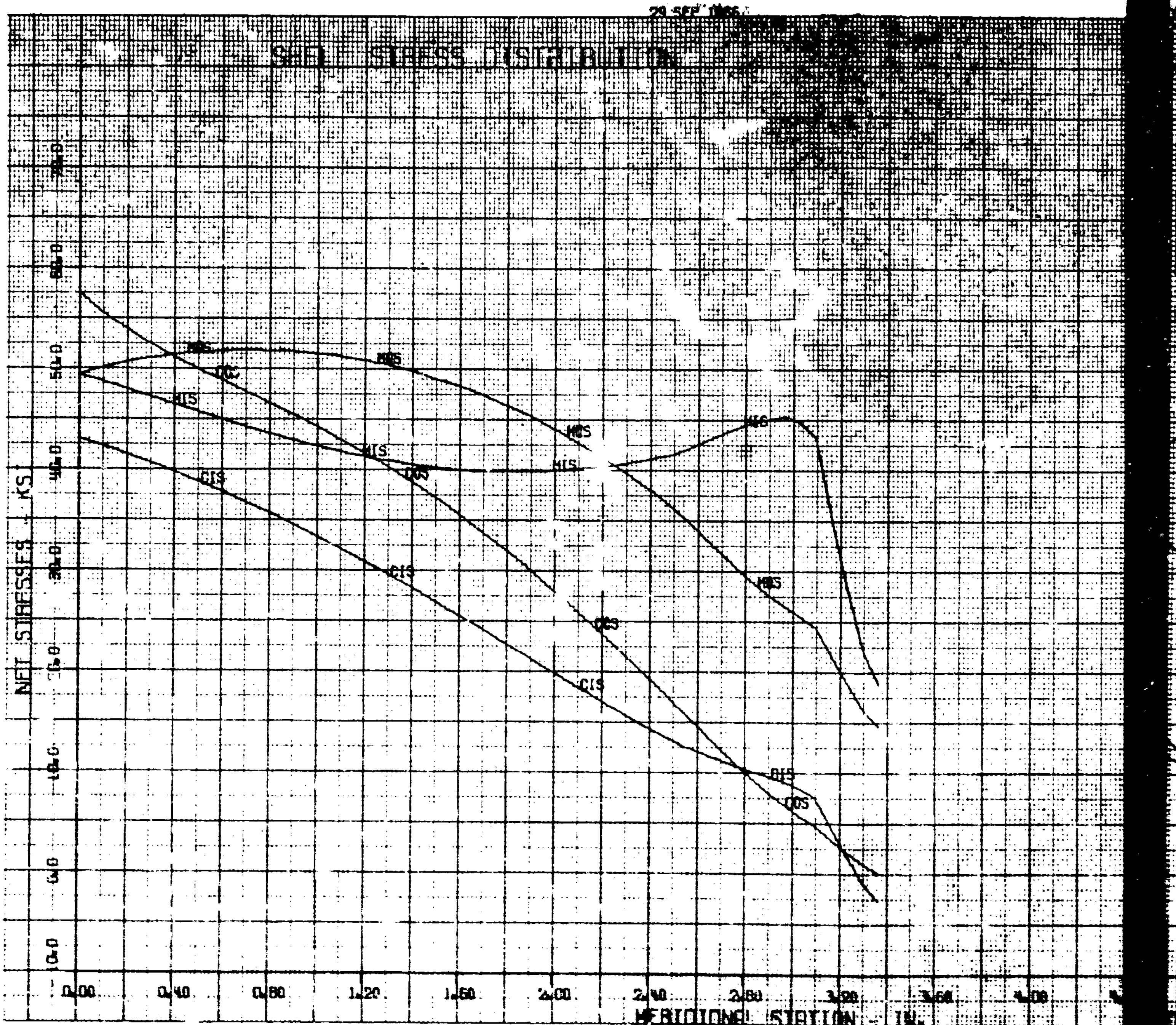
SHELL NO. 1	LEFT END	RIGHT END
DELTA	1.338225D-03	-9.940170D-04
BETA	-5.491030D-03	-3.859829D-03
M	0.000000D+00	1.360678D+01
Q	-5.518115D-08	-2.495141D+01
N	4.940000D+03	3.344054D+03

SHELL NO. 2	LEFT END	RIGHT END
DELTA	-3.966086D-03	1.850549D-02
BETA	-3.859829D-03	7.500069D-05
M	2.620343D+02	0.000000D+00
Q	-8.194997D+02	0.000000D+00
N	2.189273D+03	2.189274D+03

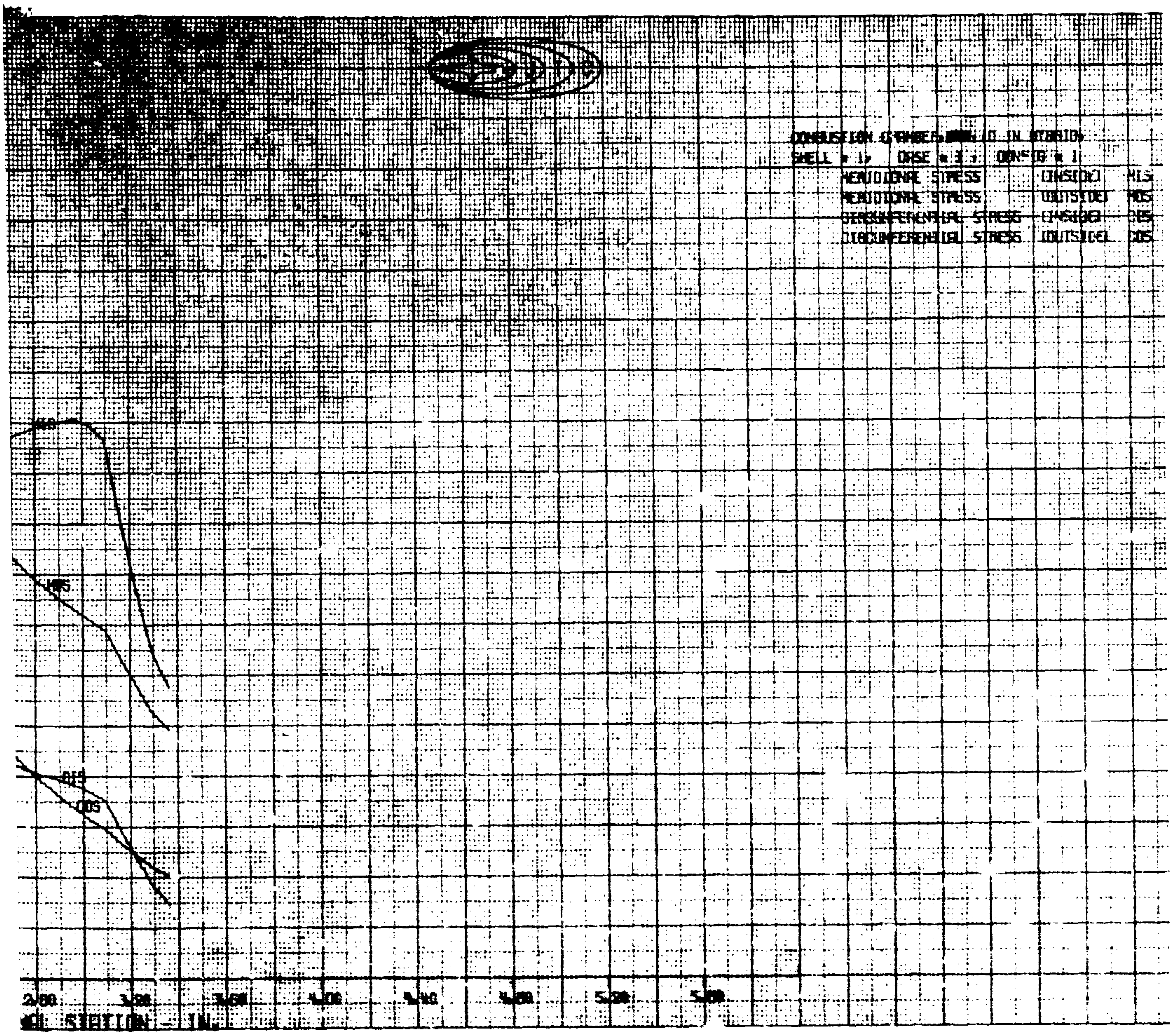
RING NO. 1	LEFT INSIDE	LEFT OUTSIDE	RIGHT INSIDE	RIGHT OUTSIDE
DELTA	-9.940170D-04	0.000000D+00	0.000000D+00	-3.966085D-03
BETA	-3.859829D-03	0.000000D+00	0.000000D+00	-3.859829D-03
M	1.360678D+01	0.000000D+00	0.000000D+00	2.620343D+02
Q	-2.495141D+01	0.000000D+00	0.000000D+00	-8.194997D+02
N	3.344054D+03	0.000000D+00	0.000000D+00	2.189273D+03

DEL-CG = -1.954974D-03 BETA-CG = -3.859829D-03

M-NET = -1.522106D+02 Q-NET = -9.902921D+02

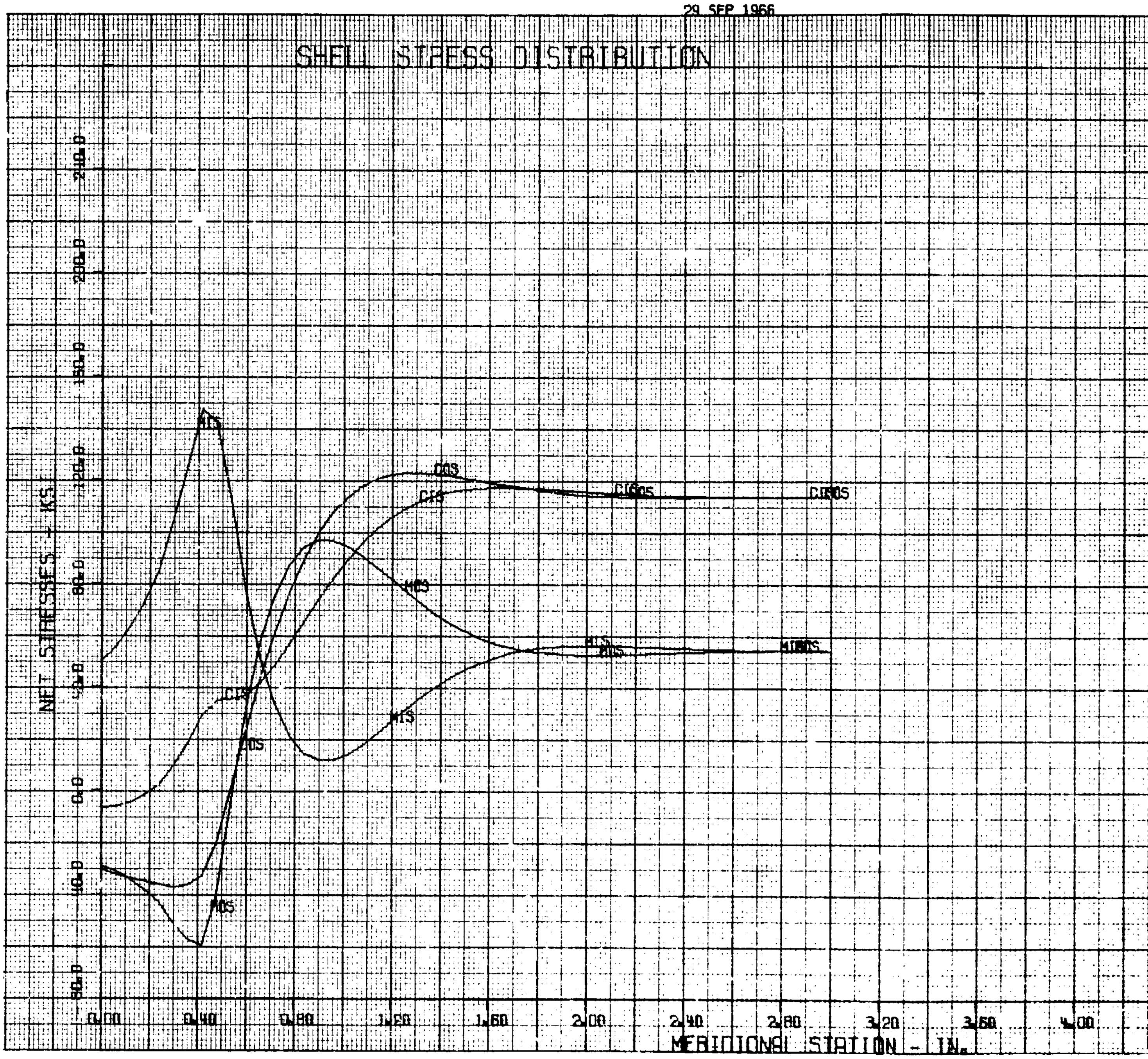


SHELL STRESS DISTRIBUTION
NET STRESSES - KSI
MERIDIONAL STATION - IN.
0.00
0.40
0.80
1.20
1.60
2.00
2.40
2.80
3.20
3.60
4.00
10.0
20.0
30.0
40.0
50.0
60.0
70.0
MOS
MIS
COS
CIS

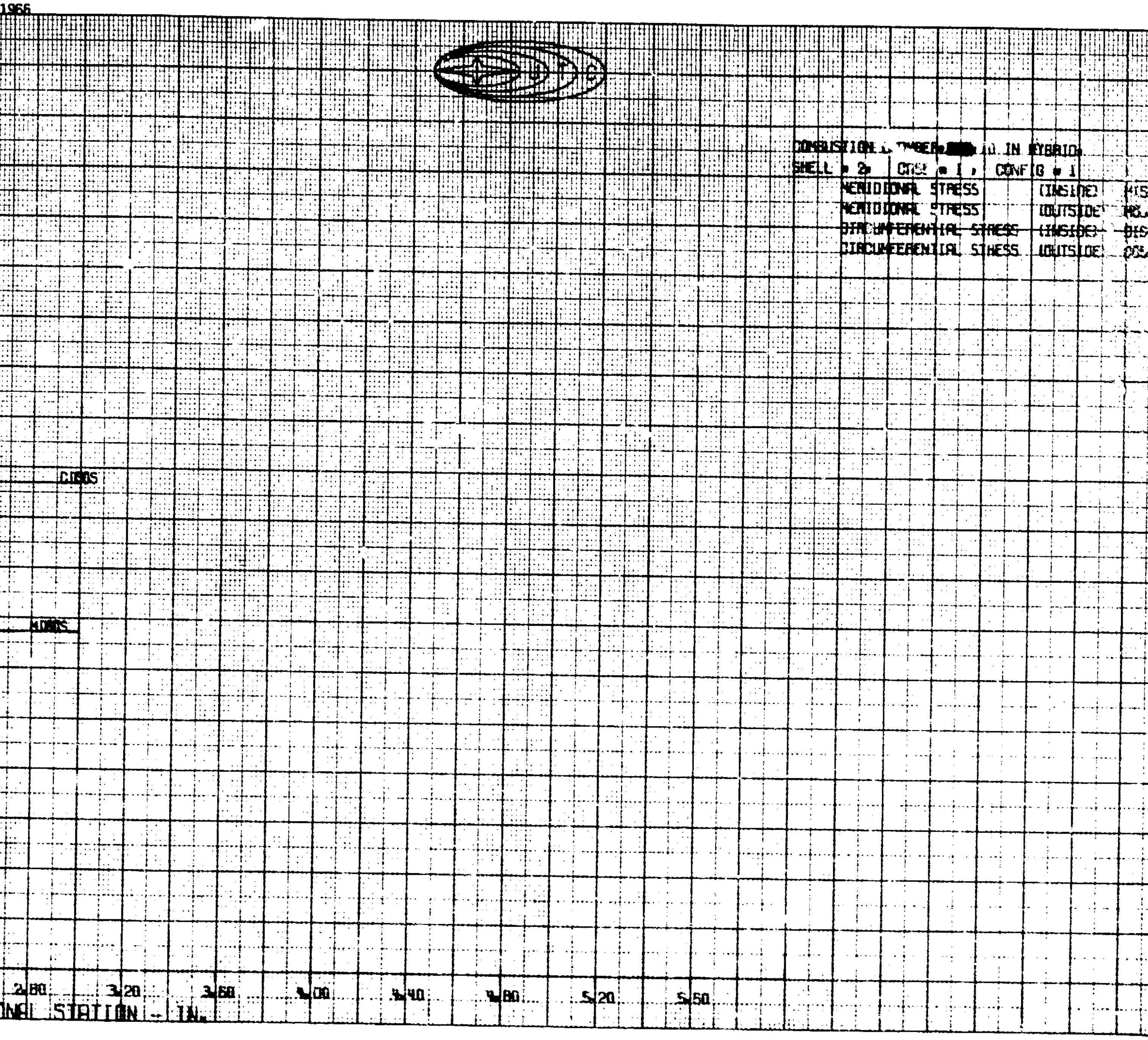

COMBUSTION CHAMBER, ... IN HYBRID,
SHELL = 1, CASE = 1, CONFIG = 1
MERIDIONAL STRESS (INSIDE) MIS
MERIDIONAL STRESS (OUTSIDE) MOS
CIRCUMFERENTIAL STRESS (INSIDE) CIS
CIRCUMFERENTIAL STRESS (OUTSIDE) COS
MIS
MOS
CIS
COS
2.80
3.00
3.60
4.00
4.40
4.80
5.20
5.60
... STATION - IN.

97/98

2

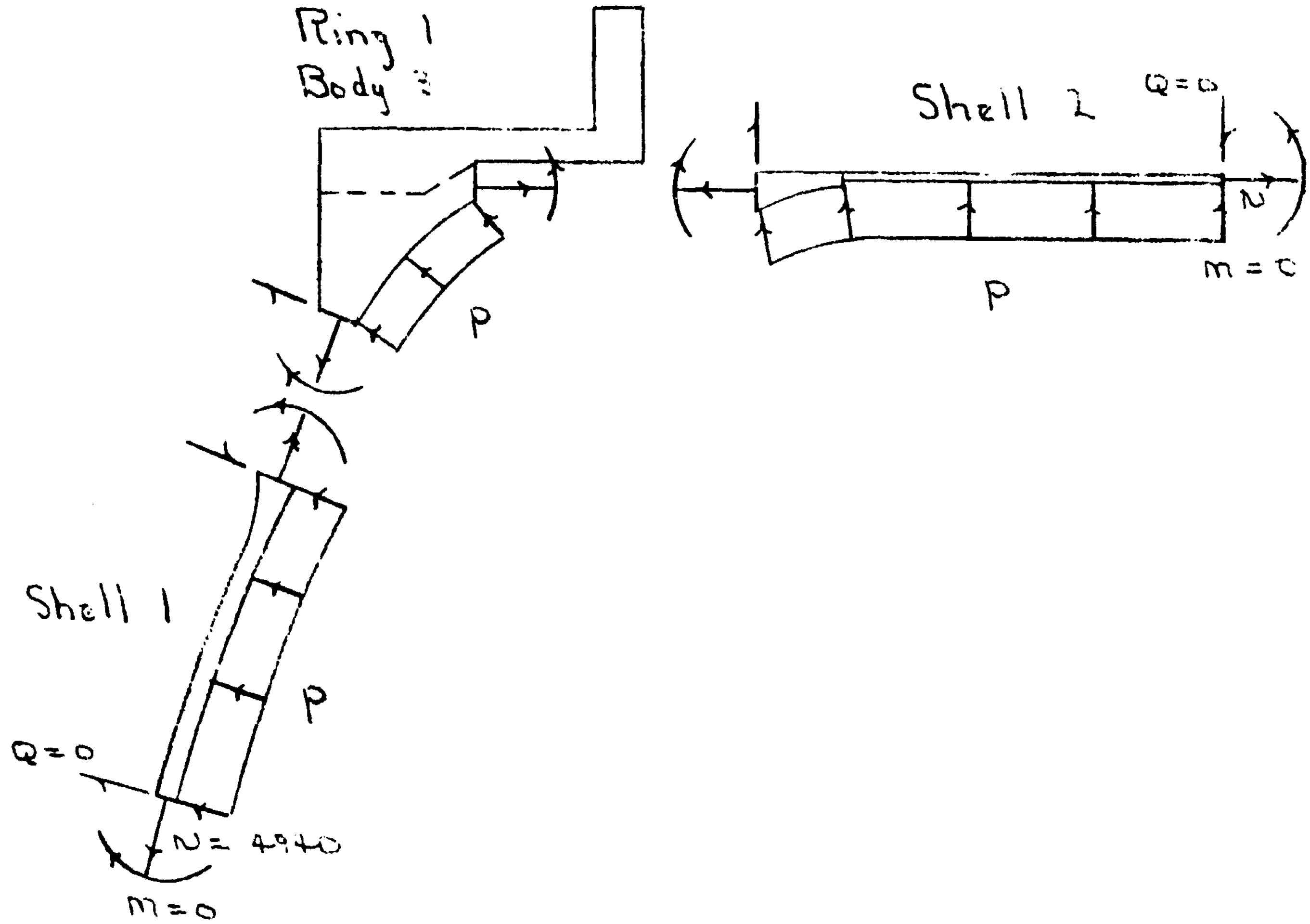

29 SEP 1966
SHELL STRESS DISTRIBUTION
NET STRESSES - KSI
MERIDIONAL STATION - IN.
0.00
0.40
0.80
1.20
1.60
2.00
2.40
2.80
3.20
3.60
4.00
-80.0
-40.0
0.0
40.0
80.0
120.0
160.0
200.0
240.0

1966



99/100

21

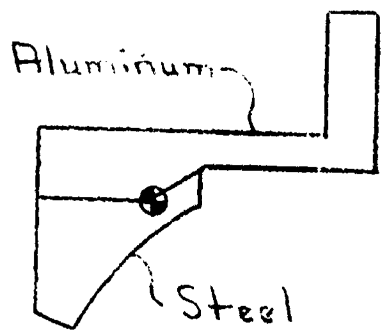


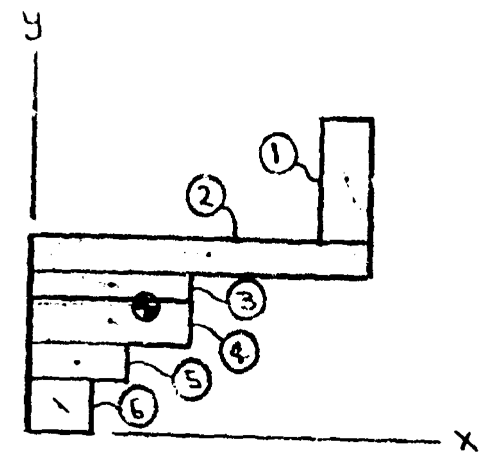
¢ Motor

FIGURE 9

FWD CLOSURE Y RING REGION
(Aluminum Adapter Ring)

Ring 1, Body 3





E_i = Modulus of Elasticity for Material of Element i, PSI

E_o = Modulus of Elasticity for Selected Base Material, PSI

$E_o = 26.5 \times 10^6$ PSI

$E_i = 10.5 \times 10^6$ PSI

$$n_i = \frac{E_i}{E_o} = \frac{10.5 \times 10^6}{26.5 \times 10^6} = .396$$

Strength of Materials, Shanley, Page 310.

Ring 1, Body 3

Item	b	h	A_i	A_{tr_i}	x	y
1	.27	.65	.1755	.0675	1.730	1.370
2	1.88	.18	.3[illegible]4	.1341	.940	.950
3	1.00	.14	.1400	.0547	.500	.780
4	1.00	.24	.2400	.2400	.500	.580
5	.53	.19	.1007	.10[illegible]	.265	.360
6	.25	.28	.0700	.0700	.125	.140
				.6690		

Item	$A_{tr_i}y$	$A_{tr_i}x$	$A_{tr_i}x^2$	$I_{y_o tr}$		
1	.09[illegible]	.12024	.208[illegible]	.00042		
2	.12740	.12605	.11849	.03949		
3	.04267	.0[illegible]	[illegible]	.00462		
4	.13920	.12000	.0[illegible]	[illegible]000		
5	.03625	.0266[illegible]	.00707	.00236		
6	.00980	.00875	.00109	[illegible]		
	.45034	.42905	.40883	.06725		

$$(I_y')_{tr} = \Sigma(A_{tr_i}x^2) + \Sigma(I_{y_o tr})$$

$$(I_y')_{tr} = .40883 + .06725 = .47560 \text{ IN}^4$$

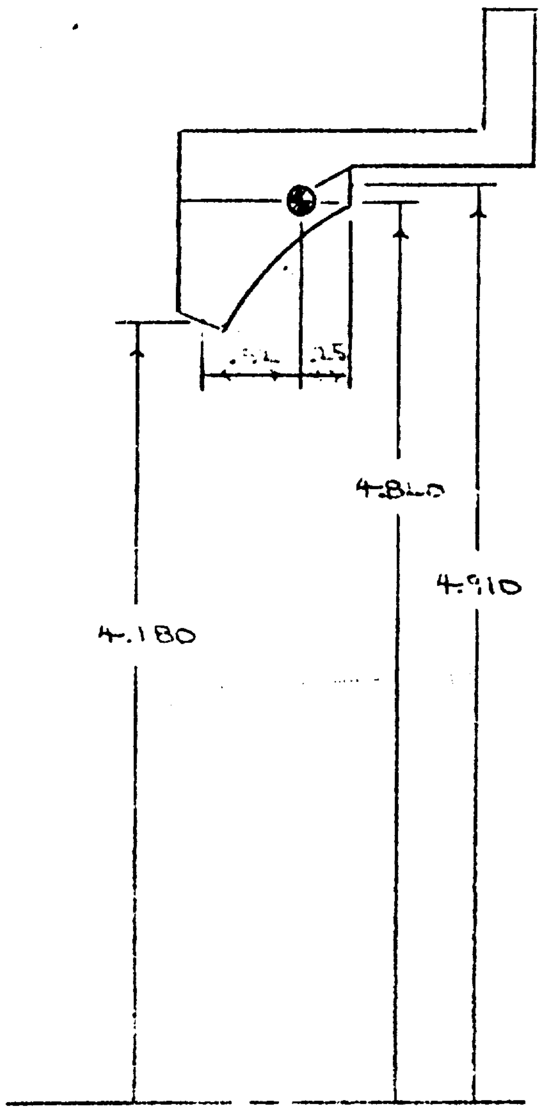
$$\bar{x} = .42905/.66[illegible] = .6414 \text{ IN}$$

$$\bar{y} = .45034/.6690 = .6735$$

$$I_{yy} = (I_y')_{tr} - \Sigma A_{tr_i}\bar{x}^2$$

$$I_{yy} = .47560 - .6690(.6414)^2 = [illegible]$$

Ring 1, Body 2



$F_x = .67\ p = .67(910) = 610$ LB.

$F_y = .67\ p = .67(910) = 610$ LB

$M_{CG} = -.947\ p(.30) = -.284(910)$

$M_{CG} = -258$

RLI = 4.180
PHILI = 35.26180
XLI = .520

RLO = 0
PHILO = 0
XLO = 0

RRI = 0
PHIRI 0
XRO = 0

RRO = 4.940
PHIRO = 90
XRO = .25

$R_{CG} = 4.820$

$A = .6690$

$I_{yy} = .20058$

$E = 26.5 \times 10^6$

Shell 1 Closure Dome (Elliptical)

10 IN HYPPID,THRUST CHAMBER,FWD R-D,ELLIPSE PROPS R.D. BUSH 22 AUG 66

INPUT DATA

A = 4.95000 B = 2.22000 X = 0.00000 DELTAS = 0.05000

GEOMETRIC PROPERTIES - ELLIPSOID OF REVOLUTION

	NDELTAS	R1	R2	PHI
	0.00000000	1.10371622D+01	1.10371622D+01	0.00000000
	0.05000000	1.10358128D+01	1.10367124D+01	0.25956752
	0.10000000	1.10317652D+01	1.10353629D+01	0.51919535
	0.15000000	1.10250207D+01	1.10331135D+01	0.77894704
	0.20000000	1.10155818D+01	1.10299640D+01	1.03888628
	0.25000000	1.10034515D+01	1.10259138D+01	1.29907698
	0.30000000	1.09886339D+01	1.10209623D+01	1.55958330
	0.35000000	1.09711341D+01	1.10151088D+01	1.82046982
	0.40000000	1.09509577D+01	1.10083522D+01	2.08180150
	0.45000000	1.09281117D+01	1.10006916D+01	2.34364383
	0.50000000	1.09026035D+01	1.09921258D+01	2.60606291
0	0.55000000	1.08744417D+01	1.09826533D+01	2.86912547
.05	0.60000000	1.08436357D+01	1.09722726D+01	3.13289902
.10	0.65000000	1.08101959D+01	1.09609822D+01	3.39745188
.15	0.70000000	1.07741334D+01	1.09487801D+01	3.66285329
.20	0.75000000	1.07354604D+01	1.09356644D+01	3.92917351
.25	0.80000000	1.06941898D+01	1.09216330D+01	4.19648387
.30	0.85000000	1.06503358D+01	1.09066836D+01	4.46485689
.35	0.90000000	1.06039130D+01	1.08908138D+01	4.73436639
.40	0.95000000	1.05549373D+01	1.08740210D+01	5.00508756
.45	1.00000000	1.05034255D+01	1.08563025D+01	5.27709705
.50	1.05000000	1.04493952D+01	1.08376553D+01	5.55047314
	1.10000000	1.03928650D+01	1.08180764D+01	5.82529580
	1.15000000	1.03338545D+01	1.07975626D+01	6.10164681
	1.20000000	1.02723842D+01	1.07761104D+01	6.37960990
	1.25000000	1.02084756D+01	1.07537164D+01	6.65927087
	1.30000000	1.01421511D+01	1.07303768D+01	6.94071771
	1.35000000	1.00734342D+01	1.07060878D+01	7.22404078
	1.40000000	1.00023494D+01	1.06808452D+01	7.50933289
	1.45000000	9.92892197D+00	1.06546449D+01	7.79668953
	1.50000000	9.85317848D+00	1.06274825D+01	8.08620897
	1.55000000	9.77514637D+00	1.05993534D+01	8.37799247
	1.60000000	9.69485412D+00	1.05702528D+01	8.67214446
	1.65000000	9.61233127D+00	1.05401759D+01	8.96877268
	1.70000000	9.52760844D+00	1.05091175D+01	9.26798846
	1.75000000	9.44071727D+00	1.04770724D+01	9.56990688
	1.80000000	9.35169051D+00	1.04440351D+01	9.87464701
	1.85000000	9.26056200D+00	1.04100000D+01	10.18233215
	1.90000000	9.16736668D+00	1.03749612D+01	10.49309008
	1.95000000	9.07214061D+00	1.03389128D+01	10.80705335
	2.00000000	8.97492102D+00	1.03018485D+01	11.12435955
	2.05000000	8.87574625D+00	1.02637620D+01	11.44515161
	2.10000000	8.77465584D+00	1.02246468D+01	11.76957814
	2.15000000	8.67169052D+00	1.01844959D+01	12.09779378
	2.20000000	8.56689220D+00	1.01433026D+01	12.42995956
	2.25000000	8.46030405D+00	1.01010597D+01	12.76624331
	2.30000000	8.35197048D+00	1.00577599D+01	13.10682007
	2.35000000	8.24193714D+00	1.00133958D+01	13.45187253
	2.40000000	8.13025102D+00	9.96795955D+00	13.80159157
	2.45000000	8.01696037D+00	9.92144345D+00	14.15617671

2.50000000	7.90211481D+00	9.87383944D+00	14.51583673
2.55000000	7.78576532D+00	9.82513935D+00	14.88079021
2.60000000	7.66796425D+00	9.77533483D+00	15.25126623
2.65000000	7.54876538D+00	9.72441740D+00	15.62750502
2.70000000	7.42822393D+00	9.67237839D+00	16.00975871
2.75000000	7.30639658D+00	9.61920904D+00	16.39829216
2.80000000	7.18334154D+00	9.56490045D+00	16.79338378
2.85000000	7.05911851D+00	9.50944359D+00	17.19532649
2.90000000	6.93378882D+00	9.45282938D+00	17.60442871
2.95000000	6.80741534D+00	9.39504862D+00	18.02101544
3.00000000	6.68006264D+00	9.33609210D+00	18.44542947
3.03000000	6.55179691D+00	9.27595055D+00	18.87803258
3.10000000	6.42268611D+00	9.21461473D+00	19.31920698
3.15000000	6.29279993D+00	9.15207542D+00	19.76935674
3.20000000	6.16220987D+00	9.08832350D+00	20.22890944
3.25000000	6.03098928D+00	9.02334996D+00	20.69831791
3.30000000	5.89921340D+00	8.95714596D+00	21.17806209
3.35000000	5.76695943D+00	8.88970292D+00	21.66865113
3.40000000	5.63430653D+00	8.82101254D+00	22.17062563
3.45000000	5.50133596D+00	8.75106692D+00	22.68456003
3.50000000	5.36813105D+00	8.67985864D+00	23.21106526
3.55000000	5.23477730D+00	8.60738084D+00	23.75079166
3.60000000	5.10136244D+00	8.53362738D+00	24.30443204
3.65000000	4.96797648D+00	8.45859295D+00	24.87272513
3.70000000	4.83471178D+00	8.38227321D+00	25.45645925
3.75000000	4.70166313D+00	8.30466501D+00	26.05647637
3.80000000	4.56892779D+00	8.22576656D+00	26.67367642
3.85000000	4.43660561D+00	8.14557769D+00	27.30902211
3.90000000	4.30479905D+00	8.06410010D+00	27.96354404
3.95000000	4.17361328D+00	7.98133766D+00	28.63834635
4.00000000	4.04315630D+00	7.89729678D+00	29.33461271
4.05000000	3.91353894D+00	7.81198682D+00	30.05361290
4.10000000	3.78487500D+00	7.72542053D+00	30.79670985
4.15000000	3.65728133D+00	7.63761458D+00	31.56536720
4.20000000	3.53087788D+00	7.54859019D+00	32.36115739
4.25000000	3.40578783D+00	7.45837380D+00	33.18577023
4.30000000	3.28213762D+00	7.36699787D+00	34.04102198
4.35000000	3.15005706D+00	7.27450183D+00	34.92886480
4.36793628	3.11586961D+00	7.24043581D+00	35.26179687

PROCESSOR: 0.107 MINUTES
INPUT/OUTPUT: 0.119 MINUTES
ELAPSED TIME: 0.258 MINUTES

Shell 1

INPUT VALUES FOR UNIT ANALYSIS
OF AN AXISYMMETRIC THIN SHELL PROJ. NO. ________

SHELL LENGTH 4.3679. POISSON'S RATIO 0.3.

YOUNGS MODULUS 26.5 X 10^6 NO. TAYLOR SERIES 5. NO. SEGMENTS 50.

	MERIDIONAL STATION	R_1	R_2	THICKNESS	PHI
	0	11.0372	11.0372		0
	.10	11.0318	11.0354		.51920
	.20	11.0156	11.03[illegible]		1.0[illegible]89
	.30	10.9886	11.0210		1.5[illegible]
	.40	10.9510	11.0084		2.08190
	.50	10.9026	10.9921		2.60606
	.60	10.8456	10.9723		3.1[illegible]
	.70	10.7741	10.9483		3.66295
	.80	10.674[illegible]	10.9[illegible]16		4.17646
	.90	10.6[illegible]	10.9[illegible]		4.73437
0	1.00	10.5054	10.8[illegible]		5.2[illegible]710
.1	1.10	10.3[illegible]	10.[illegible]81		5.8[illegible]30
.2	1.20	10.2[illegible]4	10.[illegible]761		6.[illegible]
.3	1.30	10.14[illegible]	10.7[illegible]4		6.94072
.4	1.40	10.0023	10.6806		7.5[illegible]
.5	1.50	9.8[illegible]	10.6[illegible]75		8.[illegible]
.6	1.60	9.6[illegible]	10.5703		8.6[illegible]14
.7	1.70	9.5[illegible]76	10.5091		9.26799
.8	1.80	9.3517	10.4440		9.8[illegible]
.9	1.90	9.1674	10.3750		10.49301
1.0	2.00	8.9749	10.3018		11.1[illegible]436
1.1	2.10	8.7747	10.[illegible]46		11.76[illegible]58
1.2	2.20	8.5669	10.143[illegible]		1[illegible]42996
1.3	2.30	8.3520	10.[illegible]78		1[illegible]
1.4	2.40	8.130[illegible]	[illegible].9680		1[illegible]
1.5	2.50	7.9021	[illegible]		14.[illegible]4
1.6	2.60	7.[illegible]	9.[illegible]		15.[illegible]
1.7	2.70	7.4[illegible]	9.[illegible]4		16.[illegible]
1.8	2.80	7.18[illegible]	9.[illegible]44		16.[illegible]
1.9	[illegible]	[illegible]	9.4[illegible]8		17.[illegible]42
2.0	[illegible]	[illegible]501	9.[illegible]1		18.44[illegible]

United Technology Center DIVISION OF UNITED AIRCRAFT CORPORATION — UA

PREPARED BY R D Bush DATE 9-23-66

REVIEWED BY DATE

Shell 1

INPUT VALUES FOR UNIT ANALYSIS OF AN AXISYMMETRIC THIN SHELL

PROJ. NO. ______

SHELL LENGTH 4.3679. POISSON'S RATIO 0.3.

YOUNGS MODULUS 26.5×10^6. NO. TAYLOR SERIES 5. NO. SEGMENTS 50.

	MERIDIONAL STATION	R_1	R_2	THICKNESS	PHI
2.1	3.10	6.4227	[illegible]		19.31921
2.2	3.20	[illegible]	[illegible]		[illegible]
2.3	3.30	5.8992	8.9571		21.178[illegible]
2.4	3.40	5.6342	8.8210		22.17083
2.5	3.50	5.3681	8.6799		23.[illegible]1107
2.6	3.60	5.1014	8.5336		24.[illegible]0442
2.7	3.70	4.8347	8.3823		[illegible]
2.8	3.80	4.5689	[illegible]		[illegible]
2.9	3.90	4.3045	8.0641		27.96254
3.0	4.00	4.0432	7.8973		29.33461
3.1	4.10	3.7849	7.7[illegible]54		30.7767
3.2	4.20	3.5301	7.5486		[illegible]
3.3	4.30	3.2821	7.3670		34.0[illegible]102
3.35	4.35	3.1601	7.2743		[illegible]
3.3679	4.3679	3.1159	7.2404		35.[illegible]6190

N-225 (5/63)

COMBUSTION CHAMBER — 10 IN HYBRID
(CD 2219)

$$M = 10\,NS + 4\,NR + 5\,NRJ$$

$$M = 10\overset{20}{(2)} + 4\overset{4}{(1)} + 5\overset{10}{(2)} = 34$$

NC, NS, 1, 2,

P_1, P_2, 910, 910,

NJ, 2,

NJ Sets, 1, 3, 3, 2,

Location, 1, 0, 3, 0,

No. of B.C., 5,

Body No., 1, 1, 2, 2, 2,

Location, 0, 0, 1, 1, 1,

B.C. No., 3, 4, 3, 4, 5,

Value, 0, 0, 0, 0, 4940,

$$N_1 = \frac{PR_2}{2} = \frac{910}{2}(10.8563) = 4940$$

COMBUSTION CHAMBER, FWD, 10 IN HYBRID
CD 2219

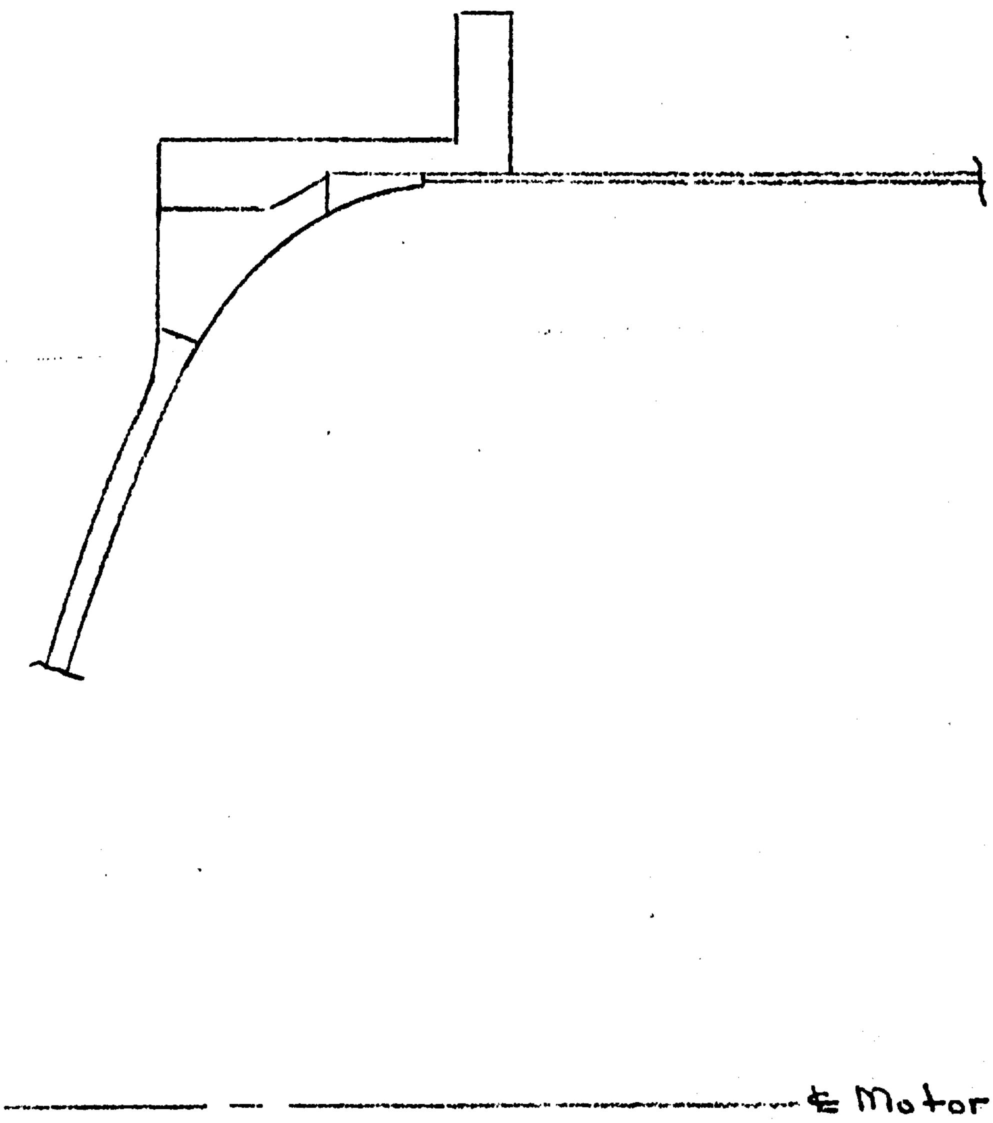
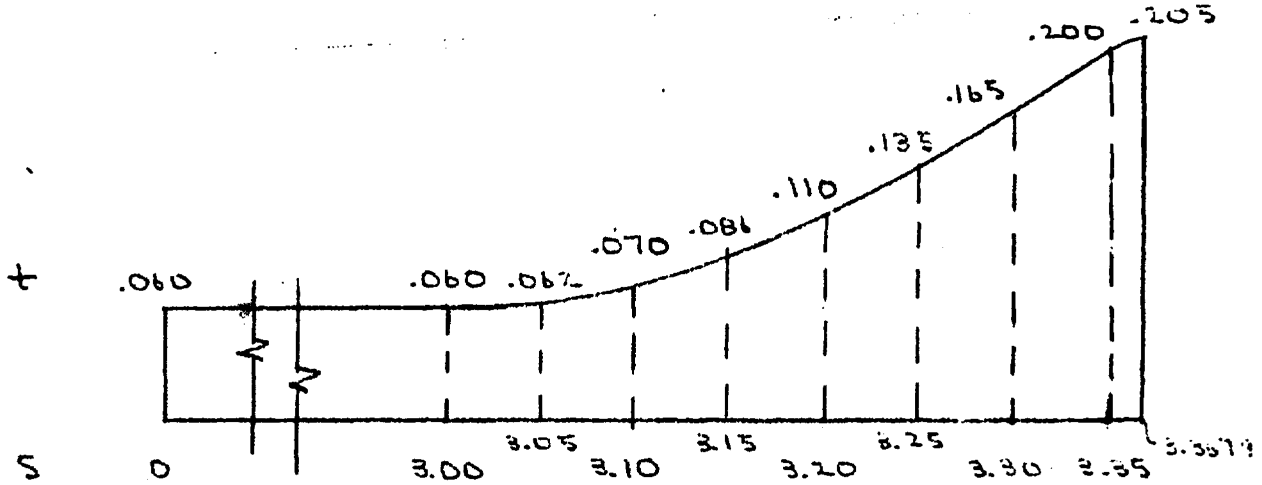


FIGURE 10

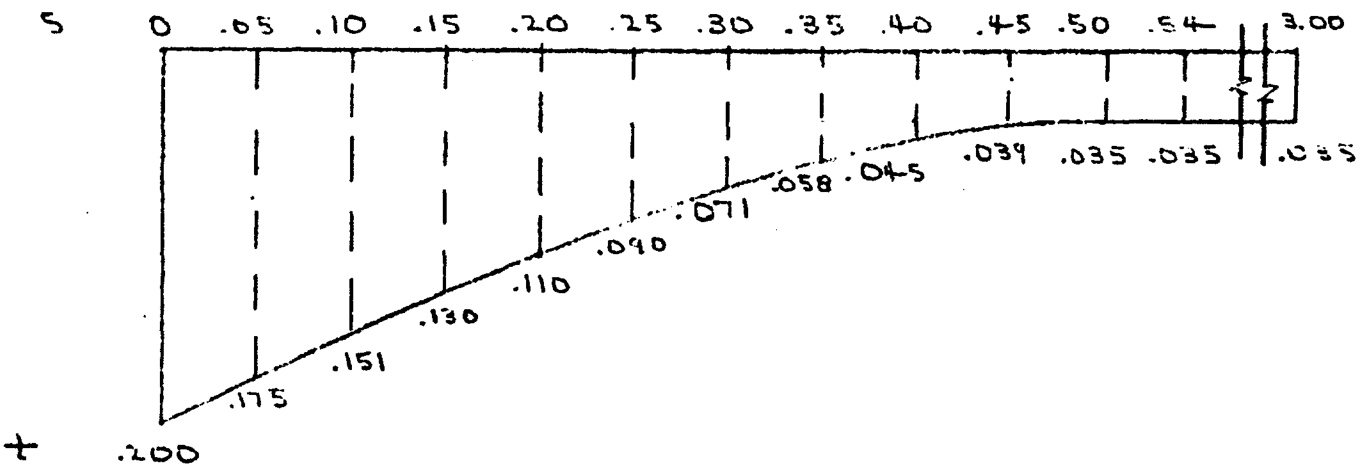
FWD CLOSURE, Y RING REGION
(Aluminum Adapter Ring)

10 IN HYBRID, COMBUSTION CHAMBER, FWD CLOSURE, Y RING REGION, ALUM. RING, 6 OCT. 66

Shell 1



Shell 2



Shell 2

S	R_1	t	t/2	R_2	ϕ
0	∞	.200	.1000	4.9400	90
.05		.175	.0875	[illegible]	
.10		.151	.0755	4.9645	
.15		.130	.0650	4.9150	
.20		.110	.0550	[illegible]	
.25		.090	.0450	4.7950	
.30		.071	.0355	5.0045	
.35		.058	.0290	5.0110	
.40		.045	.0225	5.0175	
.45		.039	.0195	5.0205	
.50		.035	.0175	5.0225	
.54		.035	[illegible]	5.0225	
3.00	∞	.035	[illegible]	5.0225	90

STRUCTURAL ANALYSIS OF MULTIPLE SHELL/RING STRUCTURES   UNITED TECHNOLOGY CENTER   6 OCT 1966

10 IN HYBRID,COMBUSTION CHAMBER,FWD CLOSURE,Y RING SECTION, 6 OCT. 66

SHELL #1 CLOSURE DOME (ELLIPTICAL)

SHELL UNIT ANALYSIS

SHELL NO. 1, CONFIGURATION NO. 1

INPUT IS:

TAYLORS SERIES EXPANSIONS OF 5 TERMS ARE USED TO SOLVE THE DIFFERENTIAL EQUATIONS SIMULTANEOUSLY.

THE 3.3679 INCH LONG SHELL SECTION IS DIVIDED INTO 50 SEGMENTS EACH OF WHICH IS 0.0674 INCHES LONG.

MODULUS OF ELASTICITY, E = 2.65000E+07

POISSON S RATIO, MU = 0.3000

MERIDIONALLY VARING PARAMETER FUNCTIONS:

RADIUS 1 =	1.0503E+01	1.0393E+01	1.0272E+01	1.0142E+01	1.0002E+01	9.8532E+00	9.6949E+00
S =	0.0000E+00	1.0000E-01	2.0000E-01	3.0000E-01	4.0000E-01	5.0000E-01	6.0000E-01
	9.5276E+00	9.3517E+00	9.1674E+00	8.9749E+00	8.7747E+00	8.5669E+00	8.3520E+00
	7.0000E-01	8.0000E-01	9.0000E-01	1.0000E+00	1.1000E+00	1.2000E+00	1.3000E+00
	8.1303E+00	7.9021E+00	7.6680E+00	7.4282E+00	7.1833E+00	6.9338E+00	6.6801E+00
	1.4000E+00	1.5000E+00	1.6000E+00	1.7000E+00	1.8000E+00	1.9000E+00	2.0000E+00
	6.4227E+00	6.1622E+00	5.8992E+00	5.6343E+00	6.3681E+00	5.1014E+00	4.8347E+00
	2.1000E+00	2.2000E+00	2.3000E+00	2.4000E+00	2.5000E+00	2.6000E+00	2.7000E+00
	4.5689E+00	4.3048E+00	4.0432E+00	3.7849E+00	3.5309E+00	3.2821E+00	3.1601E+00
	2.8000E+00	2.9000E+00	3.0000E+00	3.1000E+00	3.2090E+00	3.3000E+00	3.3500E+00
	3.1159E+00						
	3.3679E+00						
RADIUS 2 =	1.0856E+01	1.0816E+01	1.0776E+01	1.0730E+01	1.0681E+01	1.0627E+01	1.0570E+01
S =	0.0000E+00	1.0000E-01	2.0000E-01	3.0000E-01	4.0000E-01	5.0000E-01	6.0000E-01
	1.0509E+01	1.0444E+01	1.0375E+01	1.0302E+01	1.0225E+01	1.0143E+01	1.0058E+01
	7.0000E-01	8.0000E-01	9.0000E-01	1.0000E+00	1.1000E+00	1.2000E+00	1.3000E+00
	9.9680E+00	9.8738E+00	9.7753E+00	9.6724E+00	9.5649E+00	9.4528E+00	9.3361E+00
	1.4000E+00	1.5000E+00	1.6000E+00	1.7000E+00	1.8000E+00	1.9000E+00	2.0000E+00
	9.2146E+00	9.0833E+00	8.9571E+00	8.8210E+00	8.6799E+00	8.5336E+00	8.3823E+00
	2.1000E+00	2.2000E+00	2.3000E+00	2.4000E+00	2.5000E+00	2.6000E+00	2.7000E+00

	8.2258D+00	8.0641D+00	7.8973D+00	7.7254D+00	7.5486D+00	7.3670D+00	7.2745D+00
	2.8000D+00	2.9000D+00	3.0000D+00	3.1000D+00	3.2000D+00	3.3000D+00	3.3500D+00
	7.2404D+00						
	3.3679D+00						
THICKNESS =	6.0000D-02	6.0000D-02	6.2000D-02	7.0000D-02	8.6000D-02	1.1000D-01	1.3500D-01
S =	0.0000D+00	3.0000D+00	3.0500D+00	3.1000D+00	3.1500D+00	3.2000D+00	3.2500D+00
	1.6500D-01	2.0000D-01	2.0500D-01				
	3.3080D+00	3.3500D+00	3.3679D+00				
PHI =	5.2771D+00	5.8253D+00	6.3796D+00	6.9407D+00	7.5093D+00	8.0862D+00	8.6721D+00
S =	0.0000D+00	1.0000D-01	2.0000D-01	3.0000D-01	4.0000D-01	5.0000D-01	6.0000D-01
	9.2680D+00	9.8747D+00	1.0493D+01	1.1124D+01	1.1770D+01	1.2430D+01	1.3107D+01
	7.0000D-01	8.0000D-01	9.0000D-01	1.0000D+00	1.1000D+00	1.2000D+00	1.3000D+00
	1.3802D+01	1.4516D+01	1.5251D+01	1.6010D+01	1.6793D+01	1.7604D+01	1.8445D+01
	1.4000D+00	1.5000D+00	1.6000D+00	1.7000D+00	1.8000D+00	1.9000D+00	2.0000D+00
	1.9319D+01	2.0229D+01	2.1178D+01	2.2171D+01	2.3211D+01	2.4304D+01	2.5457D+01
	2.1000D+00	2.2000D+00	2.3000D+00	2.4000D+00	2.5000D+00	2.6000D+00	2.7000D+00
	2.6674D+01	2.7963D+01	2.9335D+01	3.0797D+01	3.2361D+01	3.4041D+01	3.4929D+01
	2.8000D+00	2.9000D+00	3.0000D+00	3.1000D+00	3.2000D+00	3.3000D+00	3.3500D+00
	3.5262D+01						
	3.3679D+00						

```
SHELL #2  CYLINDER WALL

SHELL UNIT ANALYSIS
                                                                    SHELL NO. 2,  CONFIGURATION NO. 1
INPUT TS:


          TAYLORS SERIES EXPANSIONS OF    5 TERMS ARE USED TO SOLVE THE DIFFERENTIAL EQUATIONS SIMULTANEOUSLY.

          THE     3.0000 INCH LONG SHELL SECTION IS DIVIDED INTO  50 SEGMENTS EACH OF WHICH IS  0.0600 INCHES LONG.

          MODULUS OF ELASTICITY, E =  2.65000E+07

          POISSON S RATIO, MU =      0.3000

          MERIDIONALLY VARING PARAMETER FUNCTIONS:


                  RADIUS 1 =       1.0000E+10  1.0000E+10
                         S =       0.0000E+00  3.0000E+00


                  RADIUS 2 =       4.9400E+00  4.9525E+00  4.9645E+00  4.9750E+00  4.9850E+00  4.9950E+00  5.0045E+00
                         S =       0.0000E+00  5.0000E-02  1.0000E-01  1.5000E-01  2.0000E-01  2.5000E-01  3.0000E-01

                                   5.0110E+00  5.0175E+00  5.0205E+00  5.0225E+00  5.0225E+00  5.0225E+00
                                   3.5000E-01  4.0000E-01  4.5000E-01  5.0000E-01  5.4000E-01  3.0000E+00


                 THICKNESS =       2.0000E-01  1.7500E-01  1.5100E-01  1.3000E-01  1.1000E-01  9.0000E-02  7.1000E-02
                         S =       0.0000E+00  5.0000E-02  1.0000E-01  1.5000E-01  2.0000E-01  2.5000E-01  3.0000E-01

                                   5.8000E-02  4.5000E-02  3.9000E-02  3.5000E-02  3.5000E-02  3.5000E-02
                                   3.5000E-01  4.0000E-01  4.5000E-01  5.0000E-01  5.4000E-01  3.0000E+00


                       PHI =       9.0000E+01  9.0000E+01
                         S =       0.0000E+00  3.0000E+00
```

RING 1, BODY 3

RING UNIT ANALYSIS

RING NO. 1, CONFIGURATION NO. 1

INPUT IS:

	RADIUS, IN.	PHI, DEG.	X, IN.
LI	4.180	35.262	0.520
LO	0.000	0.000	0.000
RI	0.000	0.000	0.000
RU	4.940	90.000	0.250

RCG = 4.820 A = 0.669 IYY = 0.200 E = 2.650E+07

OUTPUT IS:

	QNET	MNET	AXIAL EQUIL
M-LI	0.0000E+00	-8.6722E-01	0.0000E+00
Q-	5.0066E-01	-7.1353E-01	3.4131E+00
N-	-7.0810E-01	4.7794E-02	2.4132E+00
M-LO	0.0000E+00	0.0000E+00	0.0000E+00
Q-	0.0000E+00	0.0000E+00	0.0000E+00
N-	0.0000E+00	0.0000E+00	0.0000E+00
M-RI	0.0000E+00	0.0000E+00	0.0000E+00
Q-	0.0000E+00	0.0000E+00	0.0000E+00
N-	0.0000E+00	0.0000E+00	0.0000E+00
M-RU	0.0000E+00	1.0249E+00	0.0000E+00
Q-	-1.0249E+00	-2.5622E-01	-6.8420E-09
N-	1.8344E-09	-1.2299E-01	-4.9400E+00
FX	0.0000E+00	0.0000E+00	4.8200E+00
FY	1.0000E+00	0.0000E+00	0.0000E+00
MCG	0.0000E+00	1.0000E+00	0.0000E+00

DEL-CG = 1.3105E-0[illegible] * Q-NET BETA-CG = 4.3752E-06 * M-NET

SHELL/RING BOUNDARY CONDITIONS AND FORCES

CASE NO. 1, CONFIGURATION NO. 1

```
SHELL NO.  1
                 M-L  =  0.0000P+00
                 Q-L  =  0.0000P+00
                 N-L  =  4.9400P+03
            PRESSURE  =  9.1000P+02

SHELL NO.  2
                 M-R  =  0.0000P+00
                 Q-R  =  0.0000P+00
            PRESSURE  =  9.1000P+02

RING NO.  1
                  FX  =  6.1000P+02        FY  =  6.1000P+02        MCG  = -2.5800P+02
```

SHELL/RING DISCONTINUITY DEFORMATION AND FORCE SOLUTIONS CASE NO. 1. CONFIGURATION NO. 1

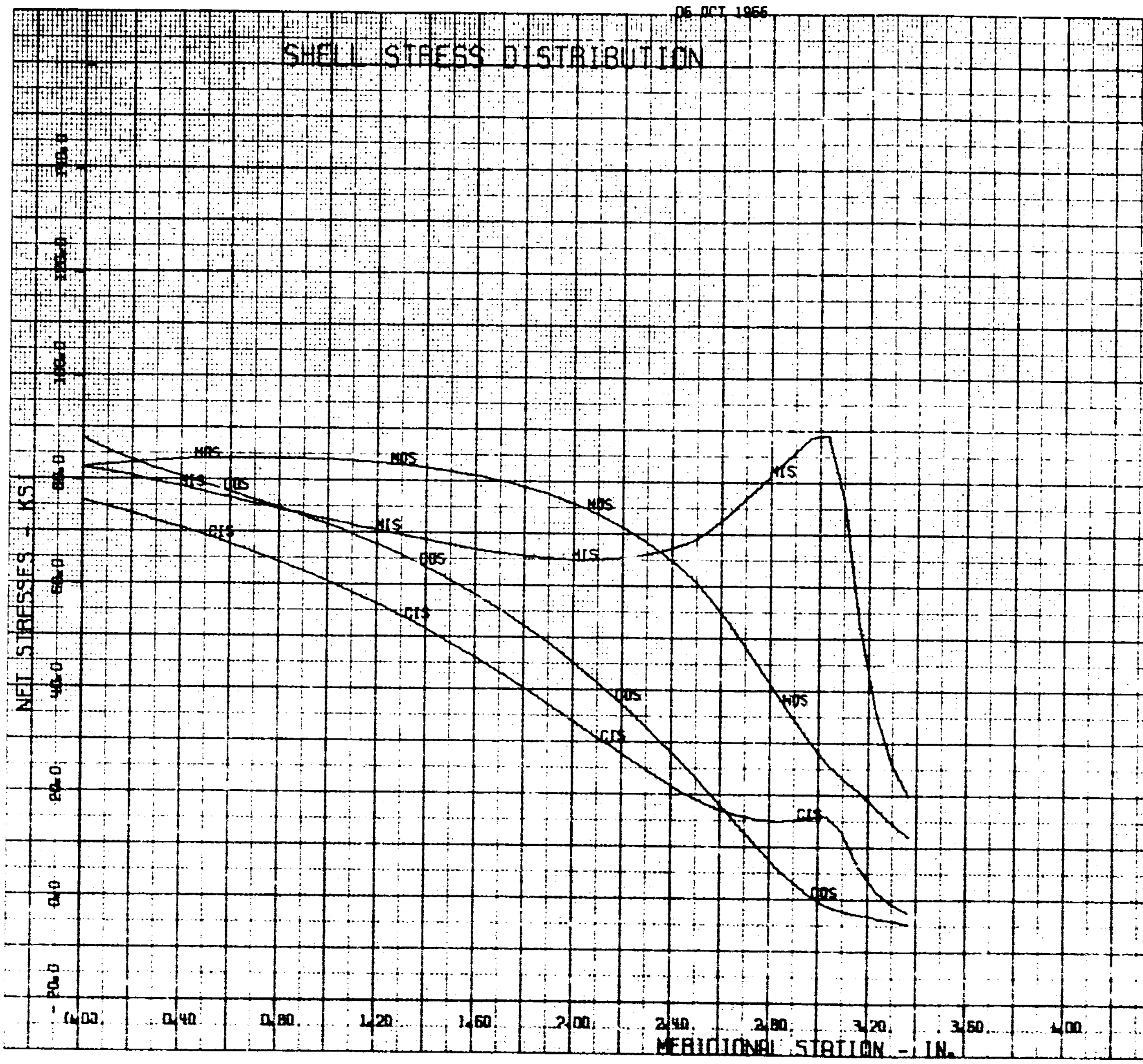
SHELL NO. 1	LEFT END	RIGHT END
DELTA	2.164964P-03	-1.315281P-03
BETA	-7.657346P-03	-2.512526P-04
M	0.000000P+00	2.646418P+01
Q	3.314354P-08	1.418456P+01
N	4.940000P+03	3.288743P+03

SHELL NO. 2	LEFT END	RIGHT END
DELTA	-1.508746P-03	2.115773P-02
BETA	-2.512527P-04	8.298568P-05
M	1.916103P+02	0.000000P+00
Q	-5.935138P+02	0.000000P+00
N	2.211520P+03	2.211520P+03

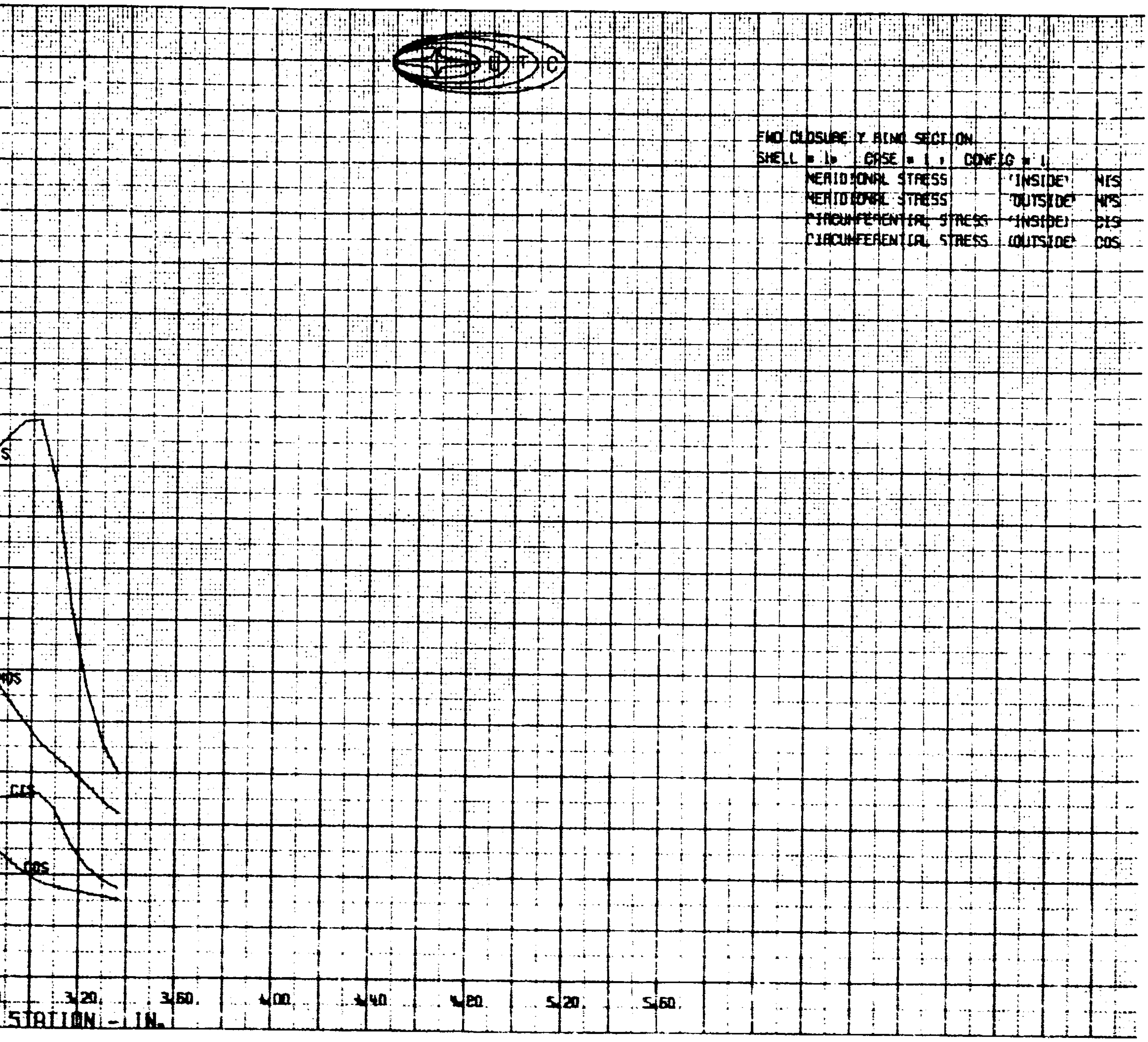
RING NO. 1	LEFT INSIDE	LEFT OUTSIDE	RIGHT INSIDE	RIGHT OUTSIDE
DELTA	-1.315281P-03	0.000000P+00	0.000000P+00	-1.508746P-03
BETA	-2.512526P-04	0.000000P+00	0.000000P+00	-2.512527P-04
M	2.646418P+01	0.000000P+00	0.000000P+00	1.916103P+02
Q	1.418456P+01	0.000000P+00	0.000000P+00	-5.935138P+02
N	3.288743P+03	0.000000P+00	0.000000P+00	2.211520P+03

DEL-CG = -1.445953P-03 BETA-CG = -2.512526P-04

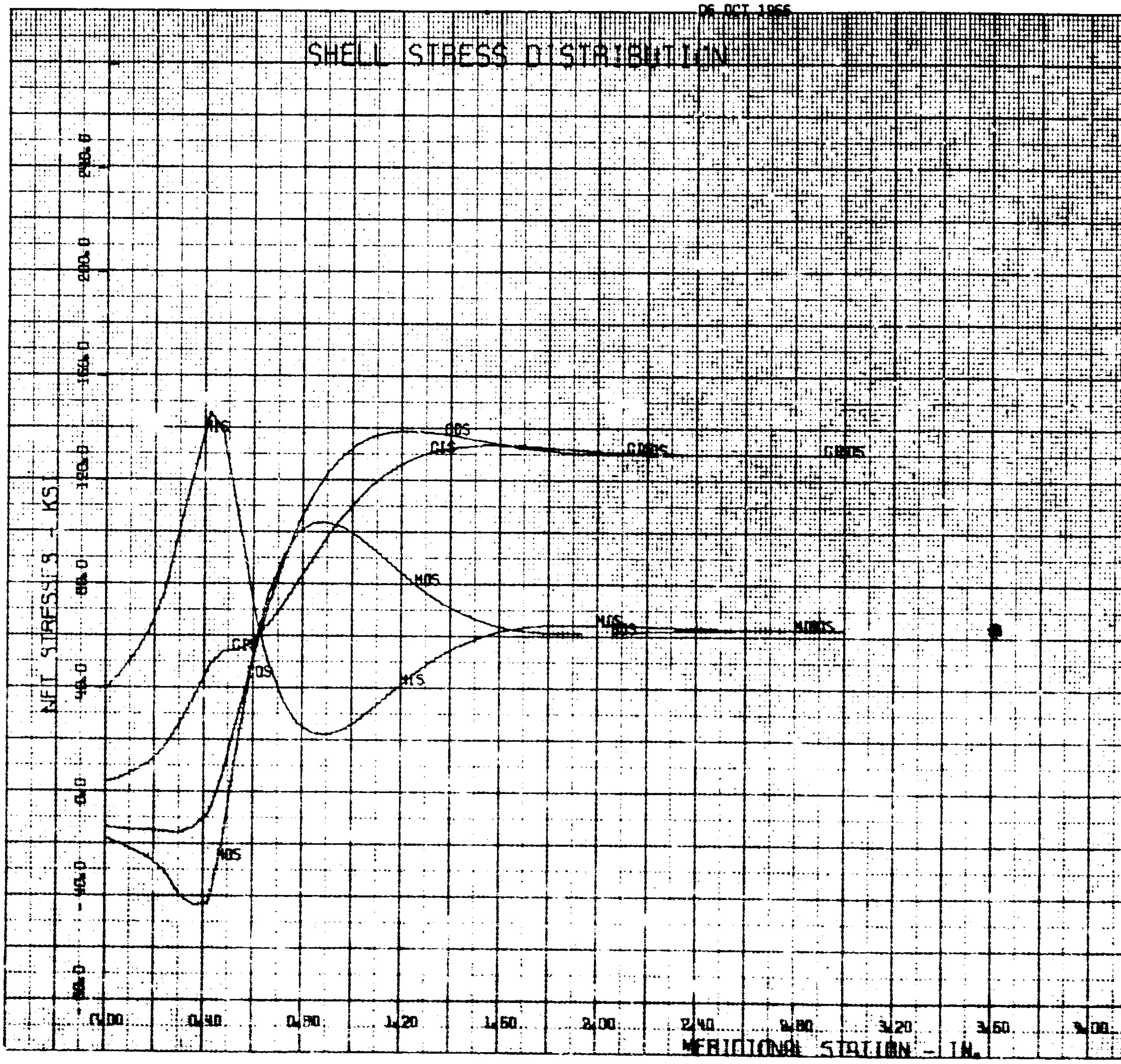
M-NET = -5.742709P+01 Q-NET = -1.103382P+03



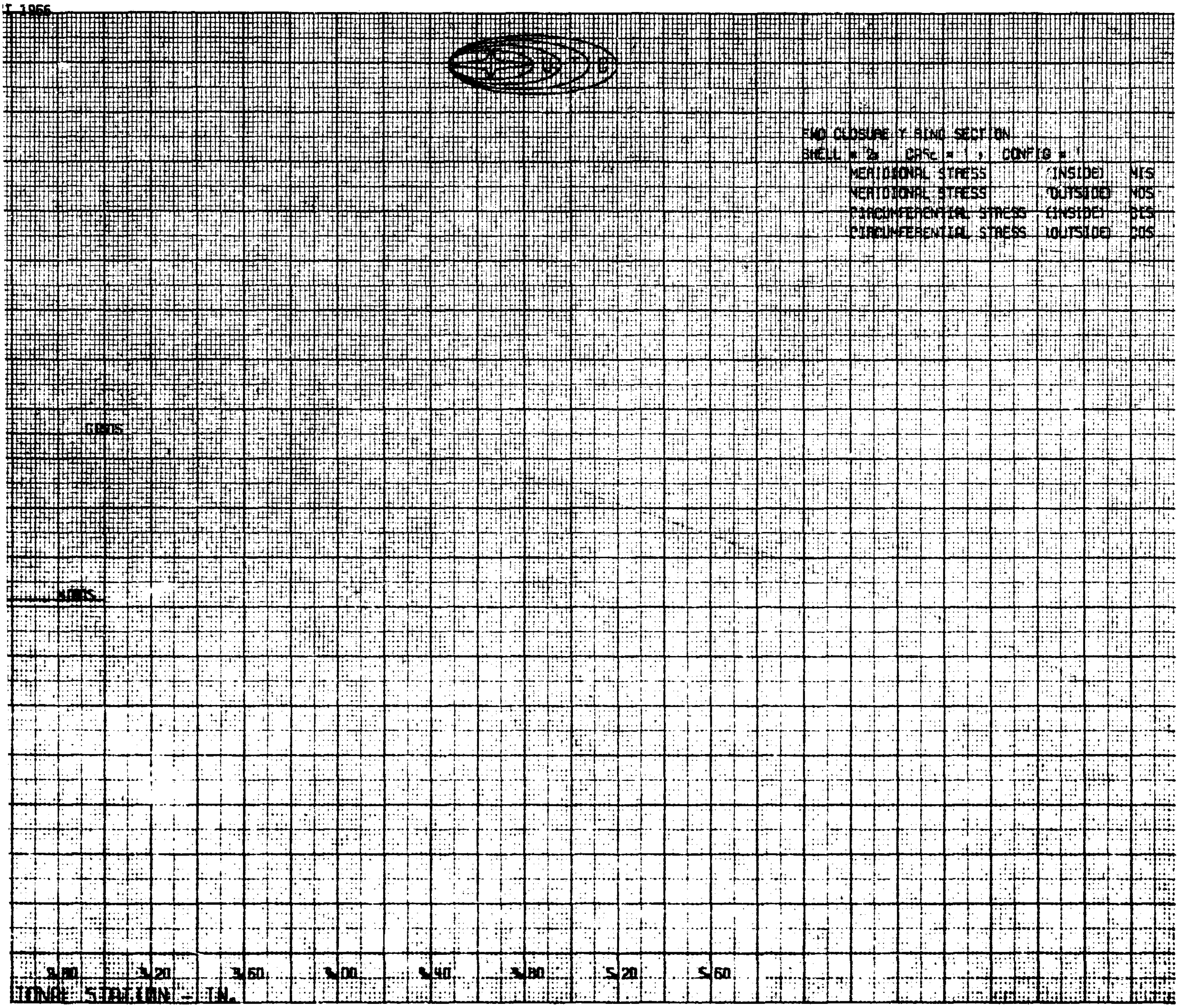
06 OCT 1966
SHELL STRESS DISTRIBUTION
NET STRESSES - KSI
MERIDIONAL STATION - IN.
MOS
MIS
OOS
OIS


END CLOSURE Y RING SECTION
SHELL = 1, CASE = 1, CONFIG = 1
MERIDIONAL STRESS 'INSIDE' MIS
MERIDIONAL STRESS 'OUTSIDE' MOS
CIRCUMFERENTIAL STRESS 'INSIDE' CIS
CIRCUMFERENTIAL STRESS 'OUTSIDE' COS
S
MOS
CIS
COS
3.20
3.60
4.00
4.40
4.80
5.20
5.60
STATION - IN.

2



06 OCT 1966
SHELL STRESS DISTRIBUTION
NET STRESSES - KSI
240.0
200.0
160.0
120.0
80.0
40.0
0.0
-40.0
-80.0
0.00
0.40
0.80
1.20
1.60
2.00
2.40
2.80
3.20
3.60
4.00
MERIDIONAL STATION - IN.
MIS
GOS
GIS
MOS



END CLOSURE Y RING SECTION
SHELL = 2, CASE = 1 , CONFIG = 1
MERIDIONAL STRESS (INSIDE) MIS
MERIDIONAL STRESS (OUTSIDE) MOS
CIRCUMFERENTIAL STRESS (INSIDE) CIS
CIRCUMFERENTIAL STRESS (OUTSIDE) COS
TONAL STATION - IN.

2

ADAPTER RING

$M_{NET} = -57$ in lb

$Q_{NET} = -1100$ lb

$A_{RING} = 0.654$ in²

$(I_{YY})_{RING}$:

Item	b	h	A_i	X	Y
1	.27	.65	.176	1.73	1.37
2	1.88	.18	.338	.94	.95
3	1.00	.14	.140	.50	.72
			.654		

Item	$A_i x$	$A x_i^2$	$I_{Y=0}$
1	.304	.526	~0
2	.317	.298	.0775
3	.070	.035	.0116
	.691	.859	.0891

$\bar{x} = \frac{.691}{.654} = 1.06''$

$I_{YY} = .089 + .859 - (.654)(1.06)^2$

$= .255 \text{ in}^4$

∴ CIRCUMFERENTIAL STRESS σ_c :

$$\sigma_c = \frac{-MR(x)}{I_{YY}} + \frac{-QR}{A}$$

$$= \frac{-(-57)(5)(1.06)}{.255} + \frac{-(-1100)(5)}{.654}$$

$$= +1185 + 8420$$

$$= \underline{+9608 \text{ psi}}$$

MATERIAL : AL ALLOY 2024 - T4

UTS (MIN.) = 60 KSI

YS (MIN.) = 40 KSI.

$$\therefore \quad M.S. = \frac{40}{9.6} - 1 = +\underline{3.16}$$

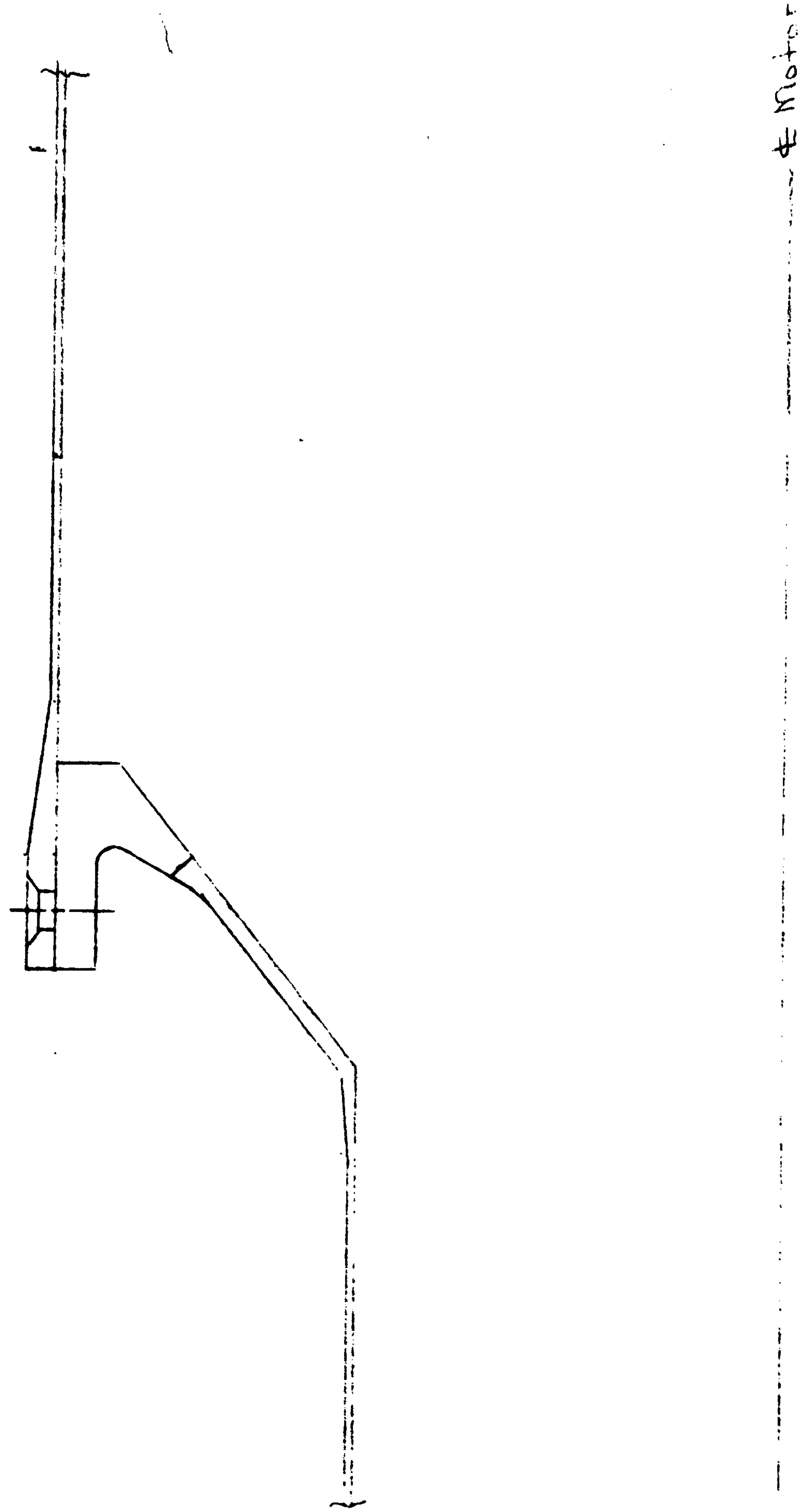


FIGURE 10 AFT CLOSURE REGION

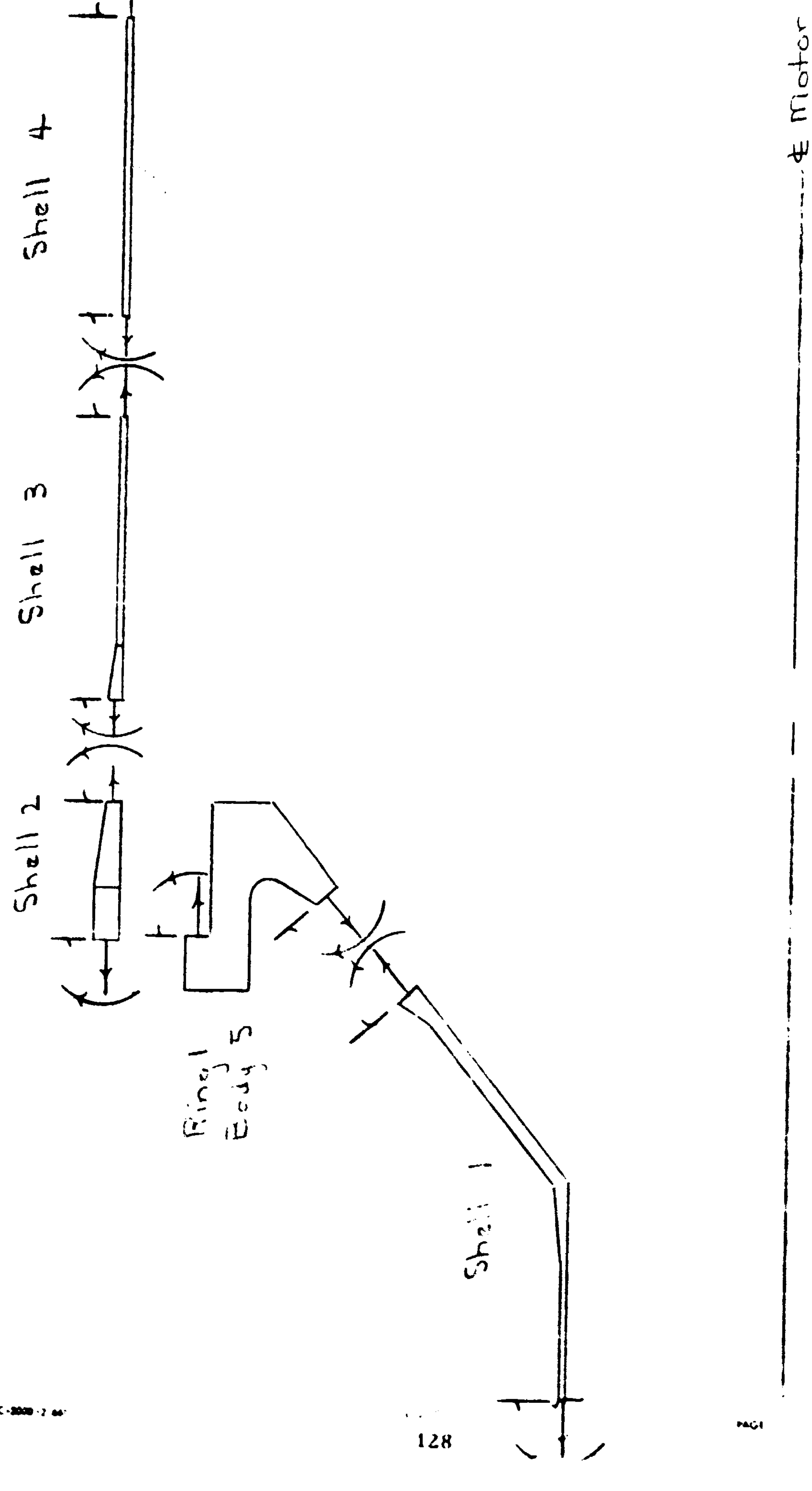
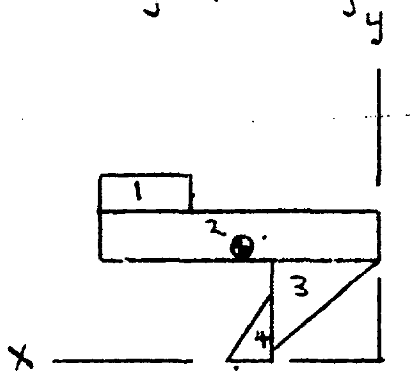
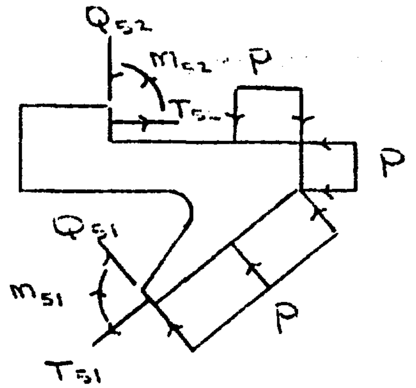


FIGURE 11 AFT CLOSURE REGION ANALYSIS CASE BODIES

Ring 1, Body 5





Item	b	h	A	x	y	Ay
1	.48	.20	.0960	1.23	.89	.08544
2	1.48	.24	.3552	.72	.67	.23798
3	.55	.48/2	.1320	.37	.36	.04752
4	.23	.34/2	.0391	.65	.11	.00430
			.6223			.37524

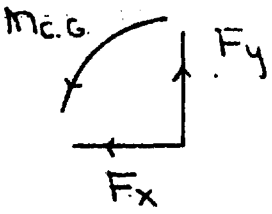
Item	Ax	Ax^2	I_{oy}			
1	.11808	.14524	.00184			
2	.25574	.18413	.06469			
3	.04884	.01807	.00224			
4	.02542	.01652	.00011			
	.44808	.26196	.06896			

$\bar{y} = .37524 / .6223 = .603$

$\bar{x} = .44808 / .6223 = .720$

$I_{y-y} = .36196 + .06896 - .6223(.720)^2 = .10832 \text{ in}^4$ (.32250)

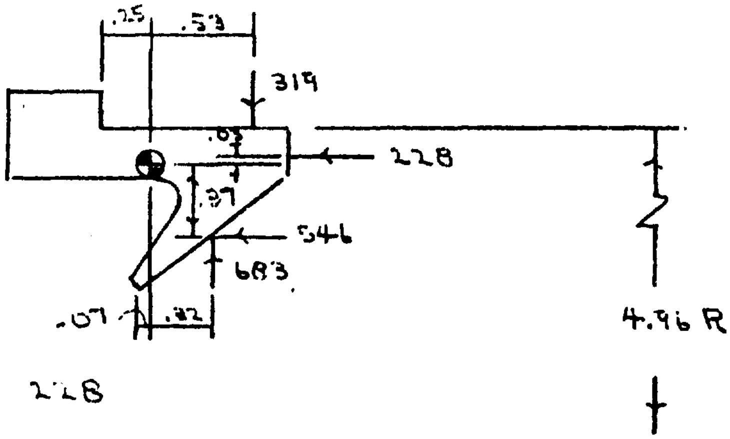
Ring 1, Body 5



$p = 650$ psi (Operating)

$p = 650(1.1) = 715$ psi (Proof)

$p = 650(1.4) = 910$ psi (Burst)



$P_1 = 910(.250) = 228$

$P_2 = 910(.600) = 546$

$P_3 = 910(.750) = 683$

$P_4 = 910(.350) = 319$

$F_x = 546 + 228 = 774$

$F_y = 683 - 319 = 364$

7 219 169 202

$M_{c.G} = 228(.03) + 683(.32) - 319(.53) - 546(.37)$

$= 226 - 371 = -145$

RLI = 4.150
PHILI = 50
XLI = .07

RLO = 0
PHILO = 0
XLO = 0

$R_{CG} = 4.96 - .18 = 4.78$
$A = .6223$
$I_{yy} = .10832$
$E = 3 \times 10^7$

RRI = 0
PHIRI = 0
XRI = 0

RRO = 5.060
PHIRO = 90
XRO = -.25

Shell 1

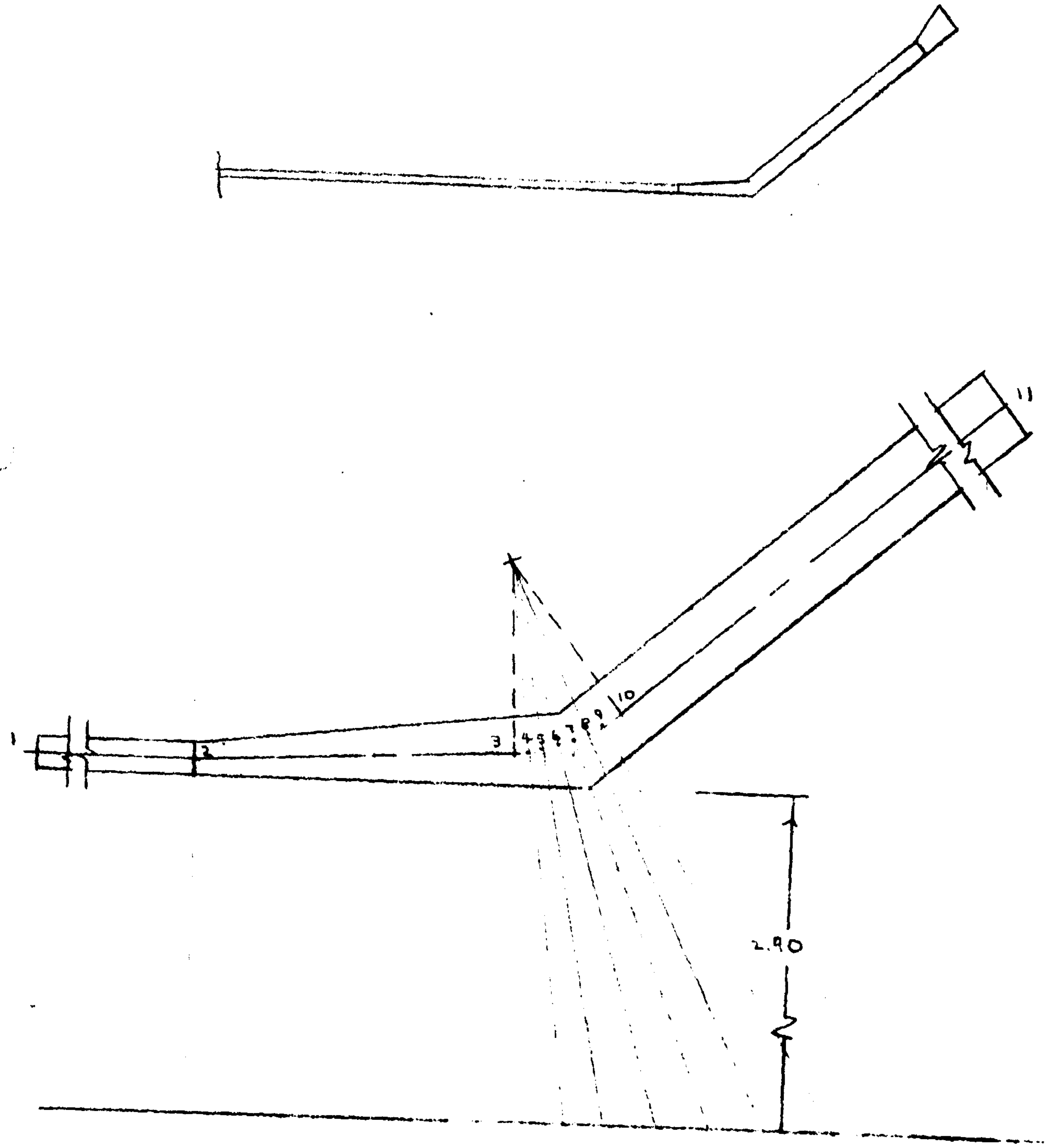
$$\beta = \frac{1.285}{\sqrt{R_2 t}} = \frac{1.285}{\sqrt{2.92(.040)}} = \frac{1.285}{\sqrt{.1168}} = \frac{1.285}{.342}$$

$$\beta = 3.76$$

$$\beta l = 5.00 \qquad l = \frac{5.00}{3.76} = 1.33 \text{ IN}$$

Item	S	R_1	R	ϕ	$\sin\phi$	R_2	t	
1	0	∞	2.920	90	1.00	2.9200	.040	
2	2.00	∞	2.920	90	1.00	2.9200	.040	
3	2.44	∞	2.9400	90	1.00	2.9400	.085	
4	2.46	-.25	2.9420	82.5	.9914	2.9675	.090	
5	2.48	-.25	2.9460	15.5	.9799	3.0[illegible]54	.090	
6	2.50	-.25	2.9540	73.0	.9585	3.08[illegible]	.090	
7	2.52	-.25	2.9600	68.5	.9304	3.1814	.095	
8	2.54	-.25	2.9660	63	.8949	3.3143	.100	
9	2.56	-.25	2.9800	58	.8526	3.475-	.100	
10	2.58	∞	2.9980	50	.7660	3.9158	.100	
11	4.37	∞	4.1500	50	.7660	5.4178	.100	

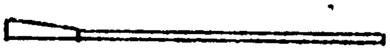
Shell 1



Shell 2

S	R_1	t	t/2	R_2	φ
0	∞	.2150	.10750	5.10750	90
.375	∞	.2150	.10750	5.10750	90
1.000	∞	.1025	.05125	5.05125	90

Shell 3



S	R_1	t	t/2	R_2	φ
0	∞	.1025	.05125	5.05125	90
.625	∞	.0350	.01750	5.01750	90
2.000	∞	.0350	.01750	5.01750	90

Shell 4

S	R_1	t	t/2	R_2	φ
0	∞	.0350	.01750	5.01750	90
2.0	∞	.0350	.01750	5.01750	90

STRUCTURAL ANALYSIS OF MULTIPLE SHELL/RING STRUCTURES UNITED TECHNOLOGY CENTER 8 OCT 1966

10 IN HYBRID,THRUST CHAMBER,AFT Y RING,ZERO SKIRT LOAD 7 OCT 66

```
SHELL #1 CYLINDER-CONE CLOSURE

SHELL UNIT ANALYSIS                                                    SHELL NO. 1,  CONFIGURATION NO. 1

INPUT IS:


          TAYLORS SERIES EXPANSIONS OF   5 TERMS ARE USED TO SOLVE THE DIFFERENTIAL EQUATIONS SIMULTANEOUSLY.

          THE    4.3700 INCH LONG SHELL SECTION IS DIVIDED INTO  50 SEGMENTS EACH OF WHICH IS  0.0874 INCHES LONG.

          MODULUS OF ELASTICITY, E =  2.65000P+07

          POISSON S RATIO, NU =     0.3000

          MERIDIONALLY VARING PARAMETER FUNCTIONS:


                RADIUS 1 =      1.0000P+10  1.0000P+10  1.0000P+10 -2.5000P-01 -2.5000P-01 -2.5000P-01 -2.5000P-01
                       S =      0.0000P+00  2.0000P+00  2.4400P+00  2.4600P+00  2.4800P+00  2.5000P+00  2.5200P+00

                               -2.5000P-01 -2.5000P-01  1.0000P+10  1.0000P+10
                                2.5400P+00  2.5600P+00  2.5800P+00  4.3700P+00


                RADIUS 2 =      2.9200P+00  2.9200P+00  2.9400P+00  2.9675P+00  3.0064P+00  3.0809P+00  3.1814P+00
                       S =      0.0000P+00  2.0000P+00  2.4400P+00  2.4600P+00  2.4800P+00  2.5000P+00  2.5200P+00

                                3.3143P+00  3.4952P+00  3.9138P+00  5.4178P+00
                                2.5400P+00  2.5600P+00  2.5800P+00  4.3700P+00


               THICKNESS =      4.0000P-02  4.0000P-02  8.5000P-02  9.0000P-02  9.0000P-02  9.0000P-02  9.5000P-02
                       S =      0.0000P+00  2.0000P+00  2.4400P+00  2.4600P+00  2.4800P+00  2.5000P+00  2.5200P+00

                                1.0000P-01  1.0000P-01  1.0000P-01  1.0000P-01
                                2.5400P+00  2.5600P+00  2.5800P+00  4.3700P+00


                     PHI =      9.0000P+01  9.0000P+01  9.0000P+01  8.2500P+01  7.8500P+01  7.3000P+01  6.8500P+01
                       S =      0.0000P+00  2.0000P+00  2.4400P+00  2.4600P+00  2.4800P+00  2.5000P+00  2.5200P+00

                                6.3000P+01  5.8000P+01  5.0000P+01  5.0000P+01
                                2.5400P+00  2.5600P+00  2.5800P+00  4.3700P+00
```

```
SHELL #2 CYLINDER WALL

SHELL UNIT ANALYSIS                                                          SHELL NO. 2,  CONFIGURATION NO. 1

INPUT IS:


        TAYLORS SERIES EXPANSIONS OF    5 TERMS ARE USED TO SOLVE THE DIFFERENTIAL EQUATIONS SIMULTANEOUSLY.

        THE    1.0000 INCH LONG SHELL SECTION IS DIVIDED INTO  50 SEGMENTS EACH OF WHICH IS  0.0200 INCHES LONG.

        MODULUS OF ELASTICITY, F =  2.65000P+07

        POISSON S RATIO, MU =     0.3000

        MERIDIONALLY VARING PARAMETER FUNCTIONS:


                RADIUS 1 =      1.0000P+10  1.0000P+10
                       S =      0.0000P+00  1.0000P+00


                RADIUS 2 =      5.1075P+00  5.1075P+00  5.0513P+00
                       S =      0.0000P+00  3.7500P-01  1.0000P+00


               THICKNESS =      2.1500P-01  2.1500P-01  1.0250P-01
                       S =      0.0000P+00  3.7500P-01  1.0000P+00


                     PHI =      9.0000P+01  9.0000P+01
                       S =      0.0000P+00  1.0000P+00
```

```
SHELL #3 CYLINDER WALL

SHELL UNIT ANALYSIS                                          SHELL NO. 3,  CONFIGURATION NO. 1

INPUT IS:

      TAYLORS SERIES EXPANSIONS OF   5 TERMS ARE USED TO SOLVE THE DIFFERENTIAL EQUATIONS SIMULTANEOUSLY.

      THE    2.0000 INCH LONG SHELL SECTION IS DIVIDED INTO  50 SEGMENTS EACH OF WHICH IS  0.0400 INCHES LONG.

      MODULUS OF ELASTICITY, E =  2.65000P+07

      POISSON S RATIO, MU =     0.3000

      MERIDIONALLY VARING PARAMETER FUNCTIONS:


            RADIUS 1 =      1.0000P+10  1.0000P+10
                   S =      0.0000P+00  2.0000P+00


            RADIUS 2 =      5.0513P+00  5.0175P+00  5.0175P+00
                   S =      0.0000P+00  6.2500P-01  2.0000P+00


           THICKNESS =      1.0250P-01  3.5000P-02  3.5000P-02
                   S =      0.0000P+00  6.2500P-01  2.0000P+00


               PHI =        9.0000P+01  9.0000P+01
                 S =        0.0000P+00  2.0000P+00
```

```
SHELL 4

SHELL UNIT ANALYSIS                                                    SHELL NO. 4,  CONFIGURATION NO. 1

INPUT IS:

      TAYLORS SERIES EXPANSIONS OF   5 TERMS ARE USED TO SOLVE THE DIFFERENTIAL EQUATIONS SIMULTANEOUSLY.

      THE    2.0000 INCH LONG SHELL SECTION IS DIVIDED INTO  50 SEGMENTS EACH OF WHICH IS  0.0400 INCHES LONG.

      MODULUS OF ELASTICITY, E =  2.65000D+07

      POISSON S RATIO, MU =     0.3000

      MERIDIONALLY VARING PARAMETER FUNCTIONS:

               RADIUS 1 =      1.0000D+10  1.0000D+10
                      S =      0.0000D+00  2.0000D+00

               RADIUS 2 =      5.0175D+00  5.0175D+00
                      S =      0.0000D+00  2.0000D+00

              THICKNESS =      3.5000D-02  3.5000D-02
                      S =      0.0000D+00  2.0000D+00

                    PHI =      9.0000D+01  9.0000D+01
                      S =      0.0000D+00  2.0000D+00
```

RING #5

RING UNIT ANALYSIS

RING NO. 1, CONFIGURATION NO. 1

INPUT IS:

	RADIUS, IN.	PHI, DEG.	X, IN.
LI	4.150	50.000	0.070
LO	0.000	0.000	0.000
RI	0.000	0.000	0.000
RO	5.108	90.000	-0.250

RCG = 4.780 A = 0.422 IYY = 0.108 E = 2.650E+07

OUTPUT IS:

	QNET	MNET	AXIAL EQUIL
M-LI	0.0000E+00	-8.6820E-01	0.0000E+00
Q-	6.6508E-01	-3.9814E-01	2.6676E+00
N-	-5.5807E-01	-3.7994E-01	3.1791E+00
M-LO	0.0000E+00	0.0000E+00	0.0000E+00
Q-	0.0000E+00	0.0000E+00	0.0000E+00
N-	0.0000E+00	0.0000E+00	0.0000E+00
M-RI	0.0000E+00	0.0000E+00	0.0000E+00
Q-	0.0000E+00	0.0000E+00	0.0000E+00
N-	0.0000E+00	0.0000E+00	0.0000E+00
M-RO	0.0000E+00	1.0685E+00	0.0000E+00
Q-	-1.0685E+00	2.6713E-01	-9.1418E-09
N-	1.9125E-09	-3.4994E-01	-5.1075E+00
FX	0.0000E+00	0.0000E+00	4.7800E+00
FY	1.0000E+00	0.0000E+00	0.0000E+00
MCG	0.0000E+00	1.0000E+00	0.0000E+00

DEL-CG = 1.3455E-06 x Q-NET BETA-CG = 7.9598E-06 x M-NET

SHELL/RING BOUNDARY CONDITIONS AND FORCES

CASE NO. 1, CONFIGURATION NO. 1

SHELL NO. 1

M-L = 0.0000D+00

Q-L = 0.0000D+00

N-L = 1.3420D+03

PRESSURE = 9.1000D+02

SHELL NO. 2

PRESSURE = 0.0000D+00

SHELL NO. 3

PRESSURE = 9.1000D+02

SHELL NO. 4

M-R = 0.0000D+00

Q-R = 0.0000D+00

PRESSURE = 9.1000D+02

RING NO. 1

FX = 7.7400D+02 FY = 3.6400D+02 MCG = -1.4500D+02

SHELL STRESS DISTRIBUTION

SHELL NO. 1, CASE NO. 1, CONFIGURATION NO. 1

OUTPUT IS:

STATION	MEMBRANE STRESSES MERIDIONAL	MEMBRANE STRESSES CIRCUMFERENTIAL	NET STRESSES MERIDIONAL INSIDE	NET STRESSES MERIDIONAL OUTSIDE	NET STRESSES CIRCUMFERENTIAL INSIDE	NET STRESSES CIRCUMFERENTIAL OUTSIDE
0.00000	3.3556635E+04	6.6409542E+04	3.3556635E+04	3.3556635E+04	6.6409542E+04	6.6409542E+04
0.87400	3.3556641E+04	6.6445112E+04	3.3556473E+04	3.3556809E+04	6.6445061E+04	6.6445162E+04
1.74800	3.3556646E+04	6.5313336E+04	3.3875414E+04	3.3237878E+04	6.5408967E+04	6.5217706E+04
2.62200	1.4584857E+04	5.8699125E+04	8.2704873E+03	2.0899227E+04	5.6064772E+04	6.1333477E+04
3.49600	2.0019144E+04	4.2112363E+04	9.5877310E+03	3.0450557E+04	3.8418734E+04	4.5805992E+04
4.37000	2.1120667E+04	8.0930466E+03	2.6585277E+04	1.5656058E+04	7.4600086E+03	8.7260846E+03

SHELL STRESS DISTRIBUTION

SHELL NO. 2, CASE NO. 1, CONFIGURATION NO. 1

OUTPUT IS:

	MEMBRANE STRESSES		NET STRESSES			
			MERIDIONAL		CIRCUMFERENTIAL	
STATION	MERIDIONAL	CIRCUMFERENTIAL	INSIDE	OUTSIDE	INSIDE	OUTSIDE
0.00000	1.0038330D+04	1.4780721D+04	6.9056541D+04	-4.8979881D+04	3.2486184D+04	-2.9247423D+03
0.20000	1.0038330D+04	5.1576550D+03	6.0489169D+04	-4.0412509D+04	2.0292907D+04	-9.9775966D+03
0.40000	1.0252926D+04	-1.0640209D+03	5.2706770D+04	-3.2200918D+04	1.1672132D+04	-1.3800174D+04
0.60000	1.2368143D+04	-3.6896210D+03	5.9553244D+04	-3.4816959D+04	1.0465909D+04	-1.7845152D+04
0.80000	1.5582966D+04	-2.0717084D+03	6.8744718D+04	-3.7578785D+04	1.3876817D+04	-1.8020234D+04
1.00000	2.1056006D+04	5.8540363D+03	7.9513518D+04	-3.7401503D+04	2.3391289D+04	-1.1683217D+04

SHELL STRESS DISTRIBUTION

SHELL NO. 3, CASE NO. 1, CONFIGURATION NO. 1

OUTPUT IS:

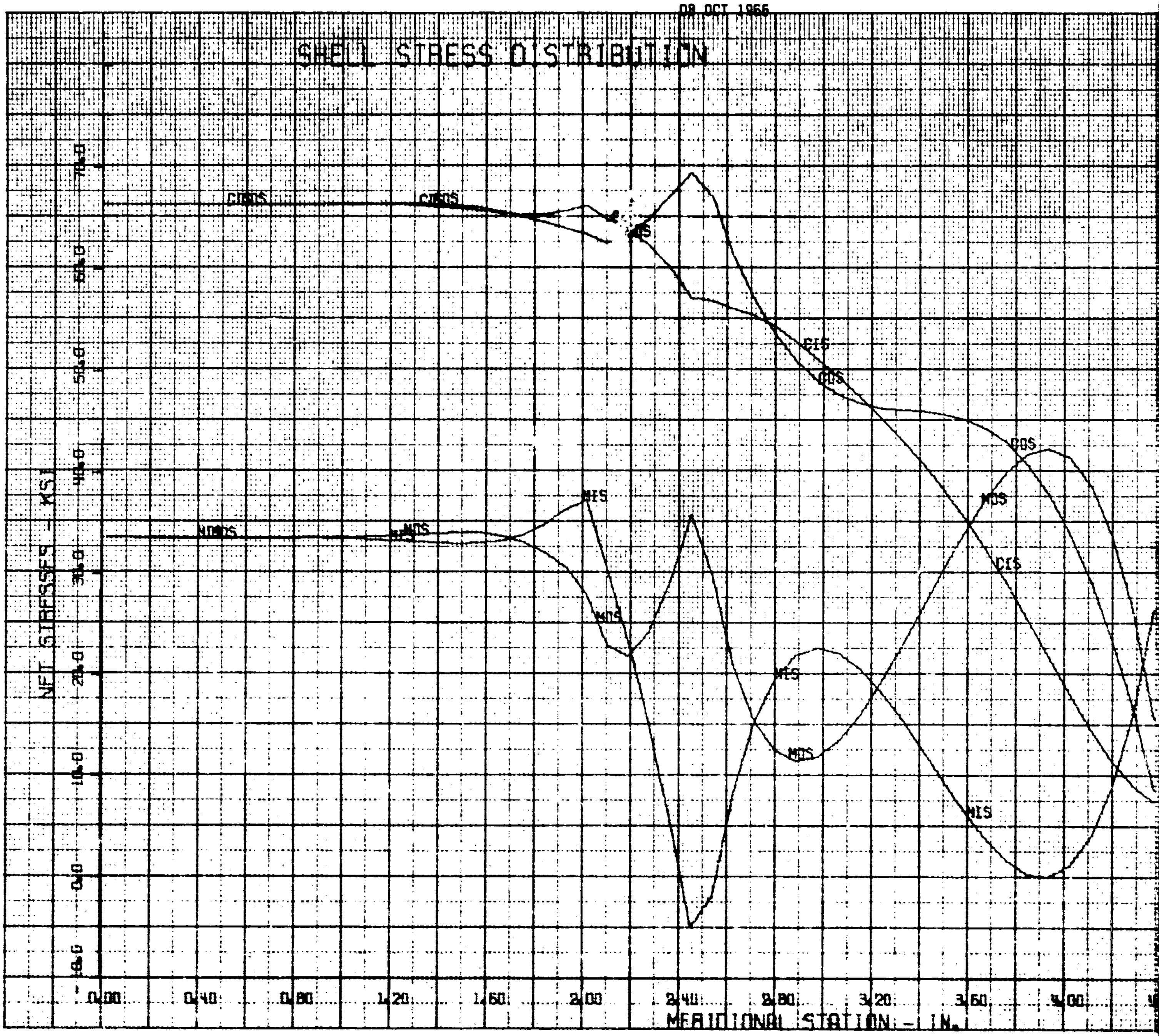
	MEMBRANE STRESSES		NET STRESSES			
			MERIDIONAL		CIRCUMFERENTIAL	
STATION	MERIDIONAL	CIRCUMFERENTIAL	INSIDE	OUTSIDE	INSIDE	OUTSIDE
0.00000	2.1056008E+04	5.8536779E+03	7.9513518E+04	-3.7401503E+04	2.3390931E+04	-1.1683575E+04
0.40000	3.6395291E+04	4.6405185E+04	6.4302962E+04	8.4876206E+03	5.4777486E+04	3.8032884E+04
0.80000	6.1664023E+04	1.0948839E+05	3.3749324E+04	8.9578722E+04	1.0111399E+05	1.1786280E+05
1.20000	6.1664026E+04	1.3262423E+05	4.8399765E+04	7.4928287E+04	1.2864495E+05	1.3660351E+05
1.60000	6.1664029E+04	1.3268723E+05	6.1450597E+04	6.1877461E+04	1.3262320E+05	1.3275126E+05
2.00000	6.1664032E+04	1.3072728E+05	6.2760395E+04	6.0567669E+04	1.3105619E+05	1.3039837E+05

SHELL STRESS DISTRIBUTION

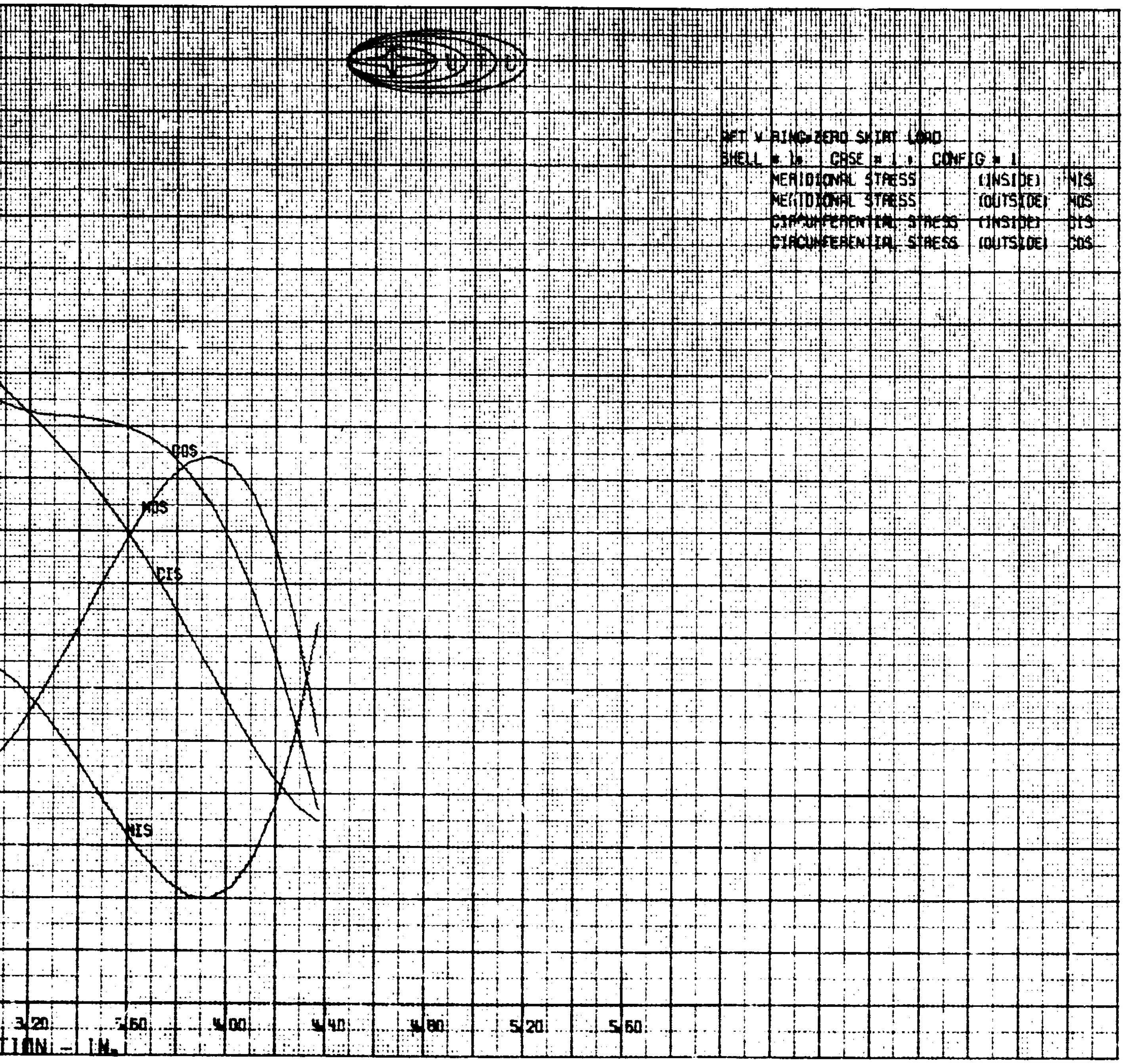
SHELL NO. 4, CASE NO. 1, CONFIGURATION NO. 1

OUTPUT IS:

STATION	MEMBRANE STRESSES MERIDIONAL	MEMBRANE STRESSES CIRCUMFERENTIAL	NET STRESSES MERIDIONAL INSIDE	NET STRESSES MERIDIONAL OUTSIDE	NET STRESSES CIRCUMFERENTIAL INSIDE	NET STRESSES CIRCUMFERENTIAL OUTSIDE
0.00000	6.1664032E+04	1.3068968E+05	6.2760395E+04	6.0567670E+04	1.3101859E+05	1.3036078E+05
0.40000	6.1664035E+04	1.3031062E+05	6.1890535E+04	6.1437536E+04	1.3037857E+05	1.3024267E+05
0.80000	6.1664038E+04	1.3040544E+05	6.1614661E+04	6.1713416E+04	1.3039062E+05	1.3042025E+05
1.20000	6.1664042E+04	1.3045692E+05	6.1634762E+04	6.1693321E+04	1.3044814E+05	1.3046570E+05
1.60000	6.1664045E+04	1.3045888E+05	6.1661368E+04	6.1666721E+04	1.3045808E+05	1.3045968E+05
2.00000	6.1664048E+04	1.3045285E+05	6.1664048E+04	6.1664047E+04	1.3045285E+05	1.3045285E+05

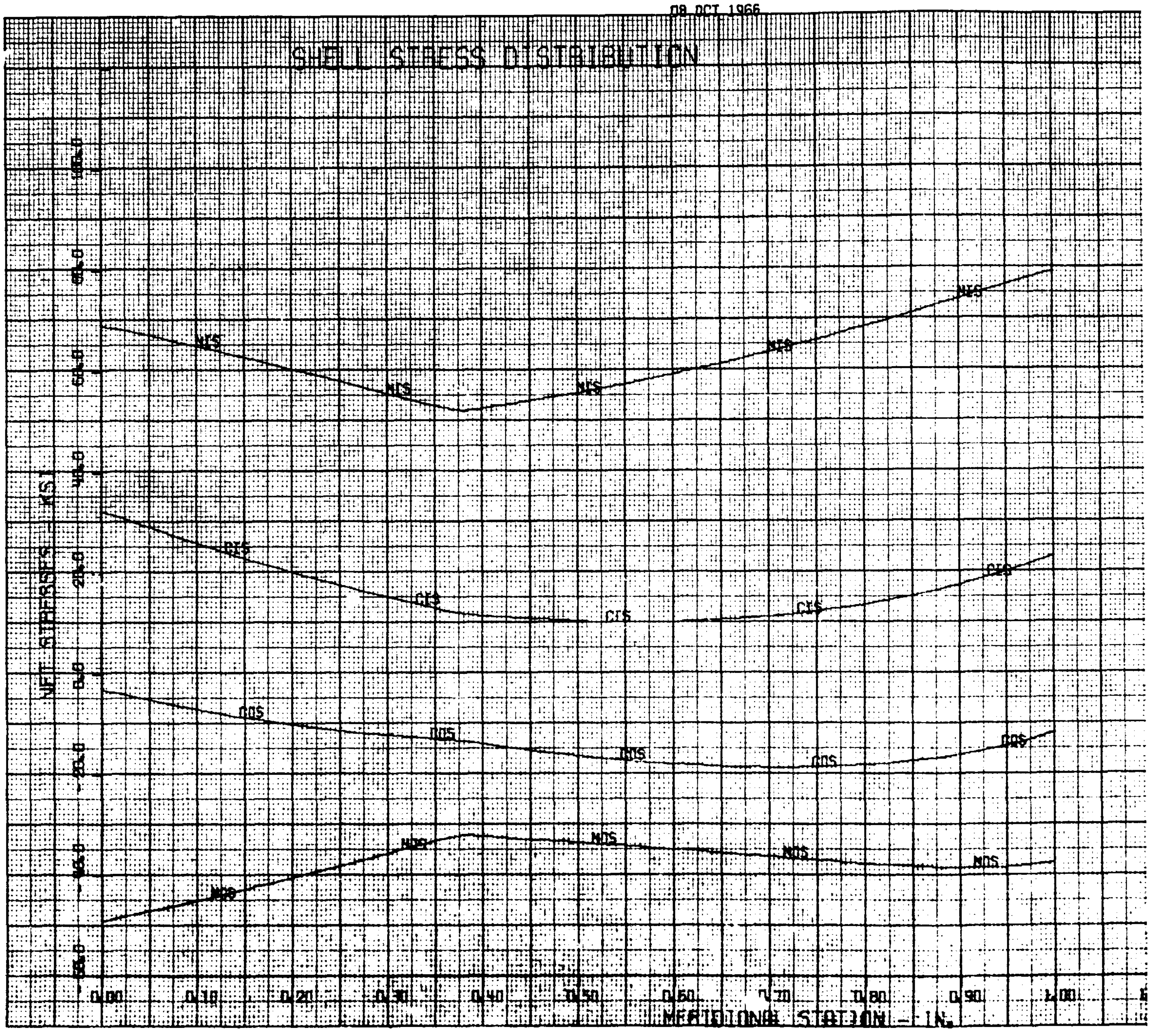


08 OCT 1966
SHELL STRESS DISTRIBUTION
NET STRESSES - KSI
MERIDIONAL STATION - IN.
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
-10.0
0.00
0.40
0.80
1.20
1.60
2.00
2.40
2.80
3.20
3.60
4.00
CIS
COS
MIS
MOS

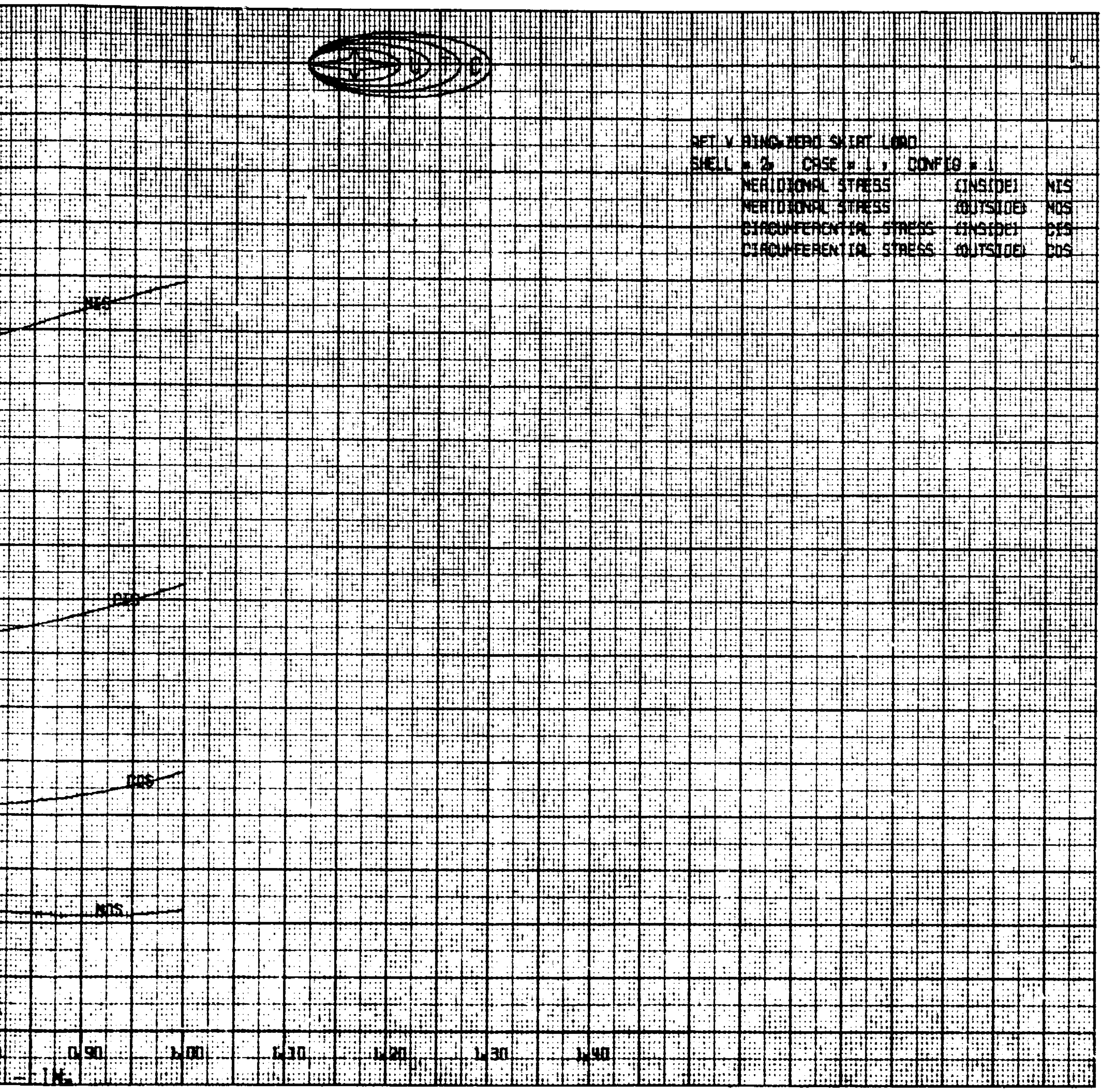


AFT V RING-ZERO SKIRT LOAD
SHELL = 1, CASE = 1, CONFIG = 1
MERIDIONAL STRESS (INSIDE) MIS
MERIDIONAL STRESS (OUTSIDE) MOS
CIRCUMFERENTIAL STRESS (INSIDE) CIS
CIRCUMFERENTIAL STRESS (OUTSIDE) COS
COS
MOS
CIS
MIS
3.20
3.60
4.00
4.40
4.80
5.20
5.60
TION - IN.

2

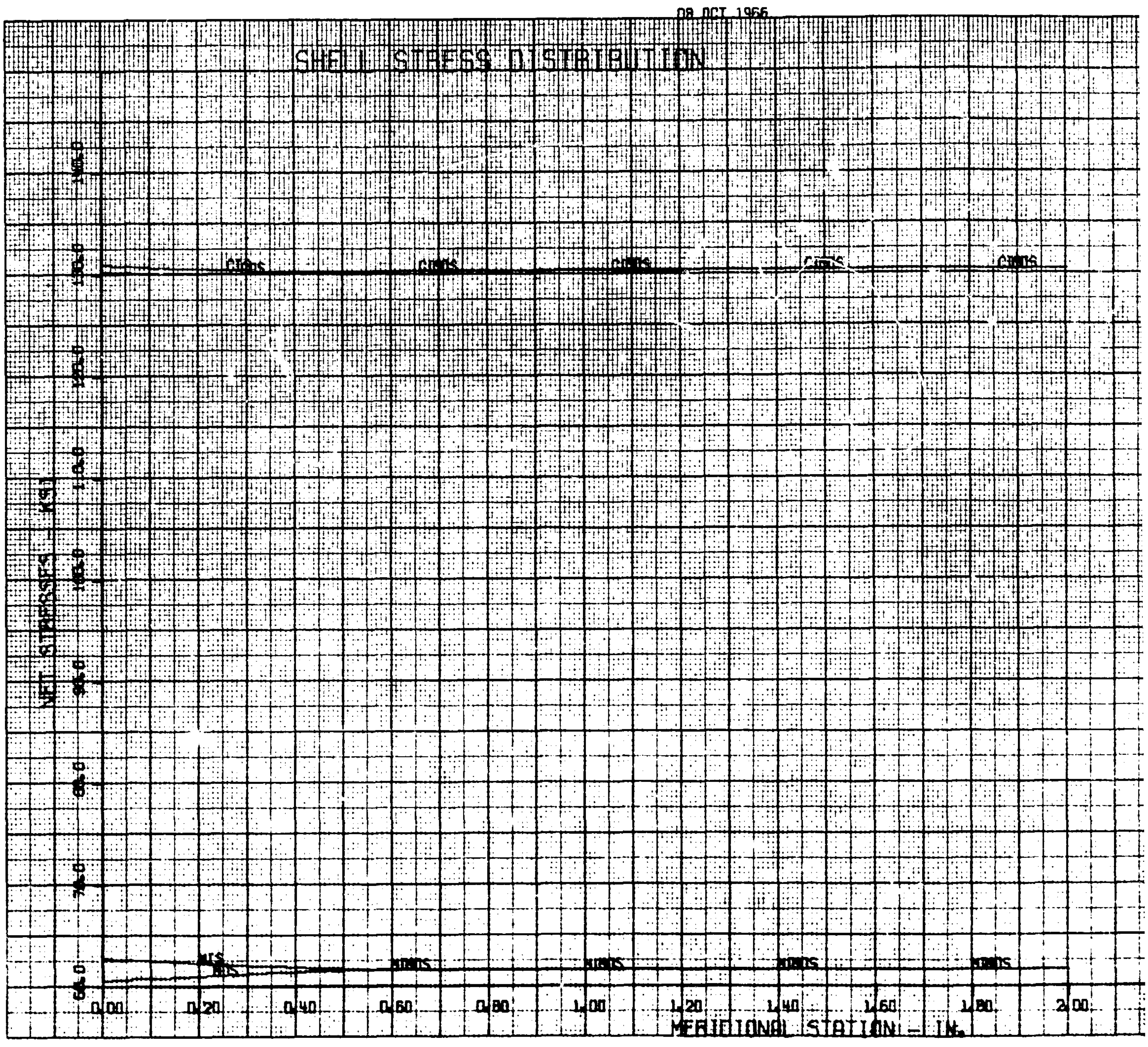


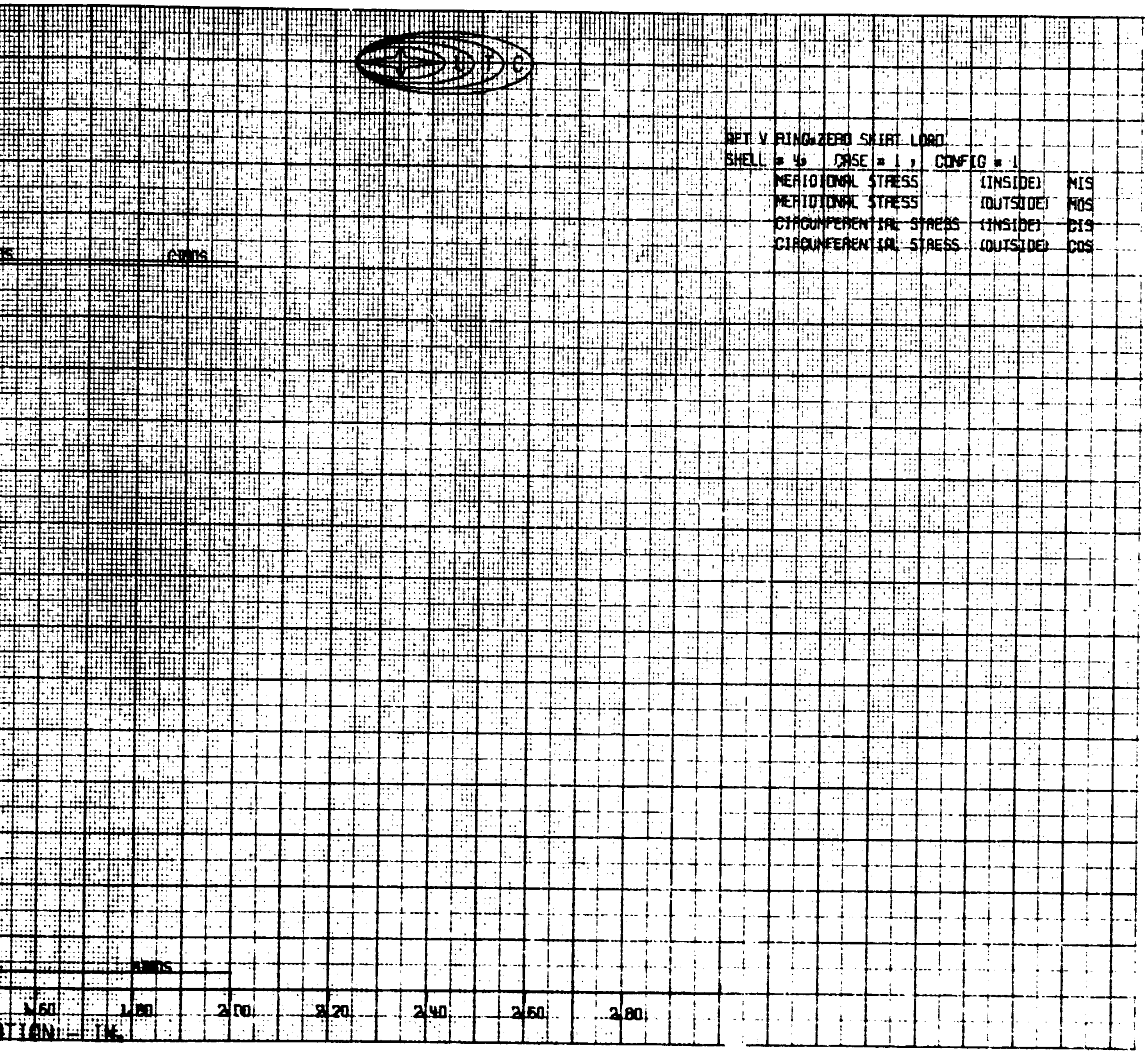
08 OCT 1966
SHELL STRESS DISTRIBUTION
VET STRESSES - KSI
100.0
80.0
60.0
40.0
20.0
0.0
-20.0
-40.0
-60.0
NIS
CIS
COS
NOS
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
MERIDIONAL STATION - IN.

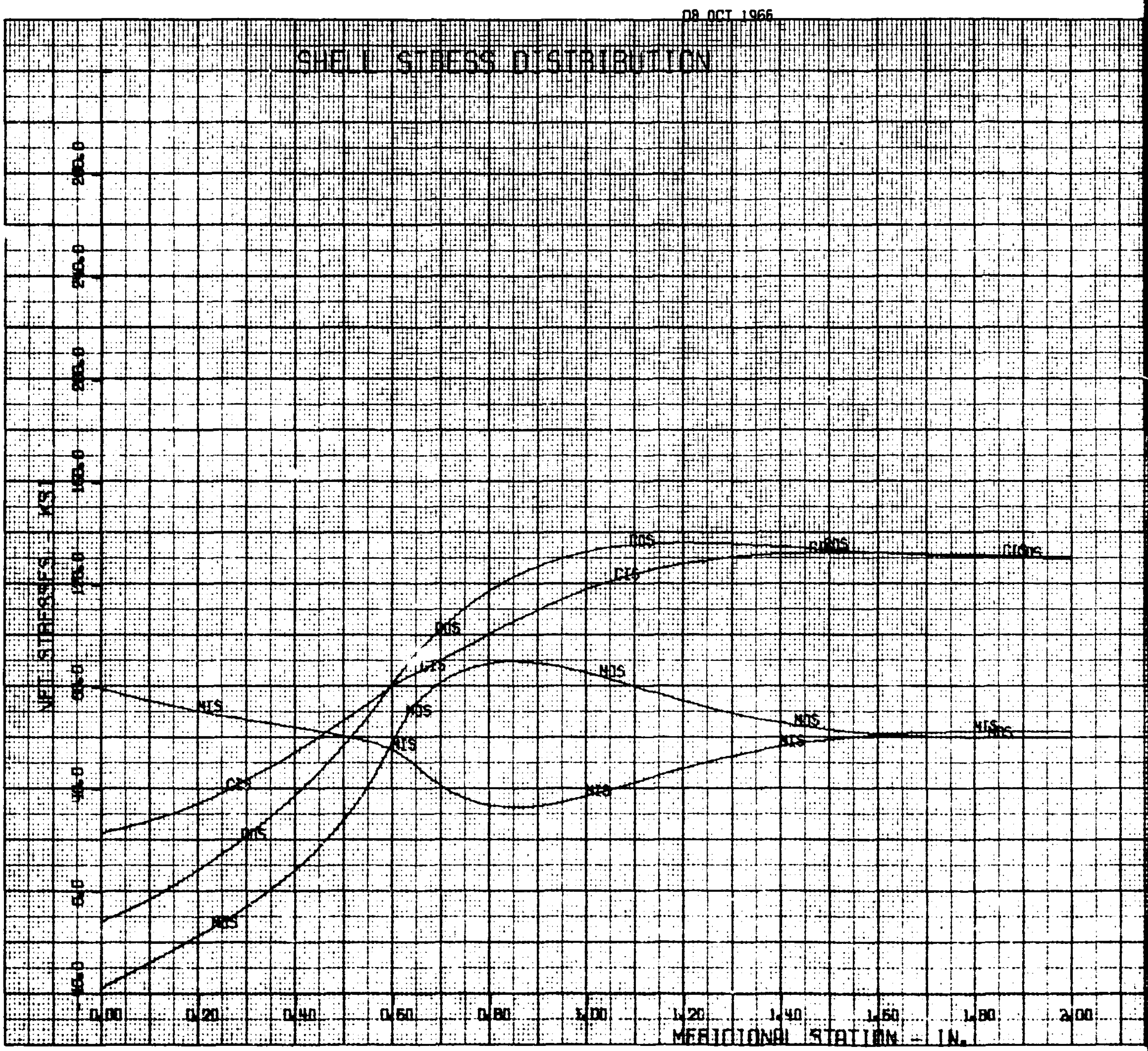


AFT Y RING-AERO SKIRT LOAD
SHELL = 2, CASE = 1 , CONFIG = 1
MERIDIONAL STRESS (INSIDE) MIS
MERIDIONAL STRESS (OUTSIDE) MOS
CIRCUMFERENTIAL STRESS (INSIDE) CIS
CIRCUMFERENTIAL STRESS (OUTSIDE) COS
MIS
CIS
COS
MOS
0.90
1.00
1.10
1.20
1.30
1.40

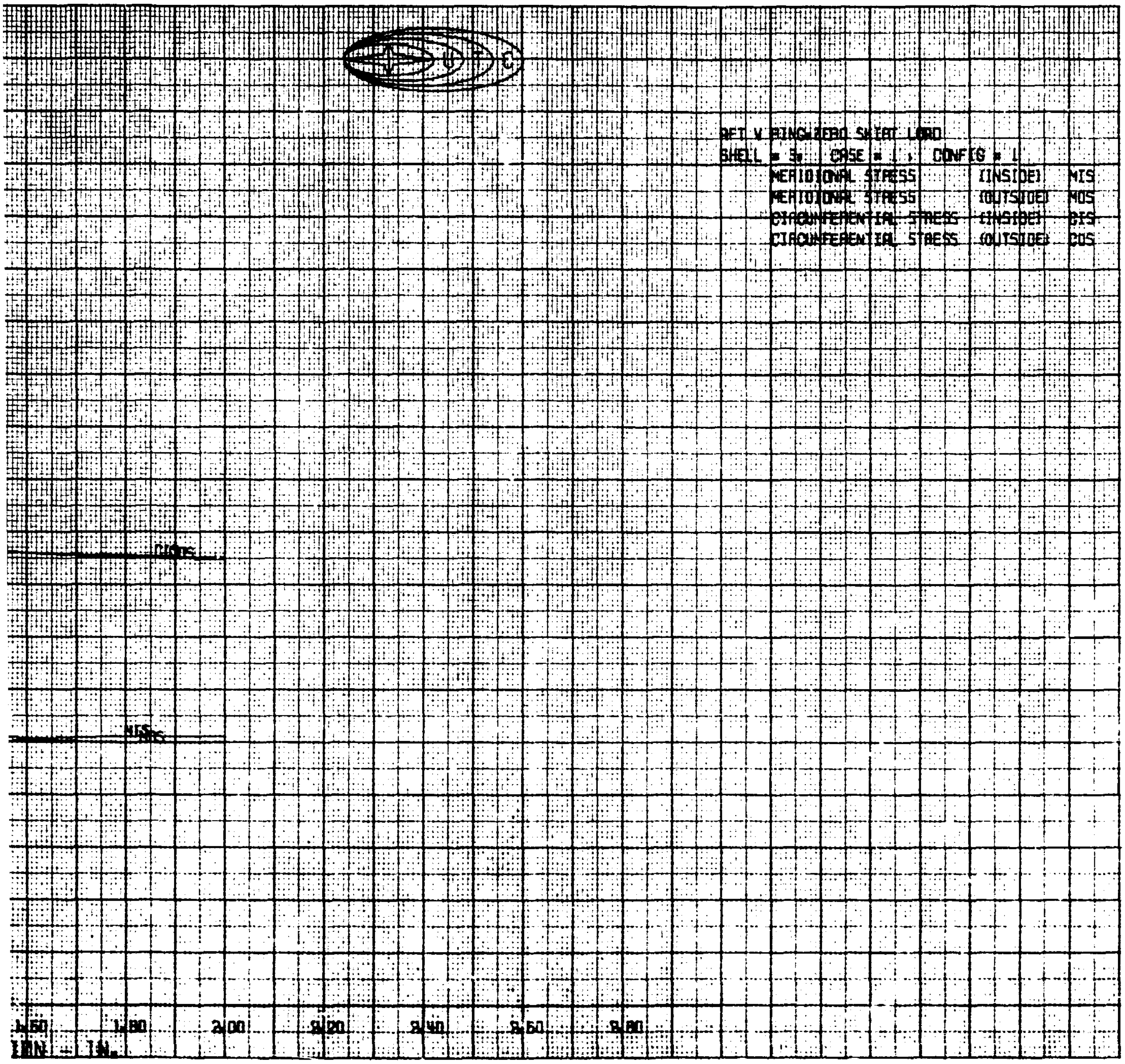
2


08 OCT 1966
SHELL STRESS DISTRIBUTION
VET STRESSES - (KSI)
CIMOS
KIMOS
MERIDIONAL STATION - IN.
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
2.00


RFT V RING,ZERO SKIRT LOAD
SHELL = 4, CASE = 1, CONFIG = 1
MERIDIONAL STRESS (INSIDE) MIS
MERIDIONAL STRESS (OUTSIDE) MOS
CIRCUMFERENTIAL STRESS (INSIDE) CIS
CIRCUMFERENTIAL STRESS (OUTSIDE) COS
1.60
1.80
2.00
2.20
2.40
2.60
2.80



08 OCT 1966
SHELL STRESS DISTRIBUTION
NET STRESSES - KSI
MERIDIONAL STATION - IN.
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
2.00
NIS
CIS
COS
NOS


SHELL = 5, CASE = 1, CONFIG = 1
MERIDIONAL STRESS (INSIDE) MIS
MERIDIONAL STRESS (OUTSIDE) MOS
CIRCUMFERENTIAL STRESS (INSIDE) CIS
CIRCUMFERENTIAL STRESS (OUTSIDE) COS
1.60
1.80
2.00
2.20
2.40
2.60
2.80

SHELL/RING DISCONTINUITY DEFORMATION AND FORCE SOLUTIONS

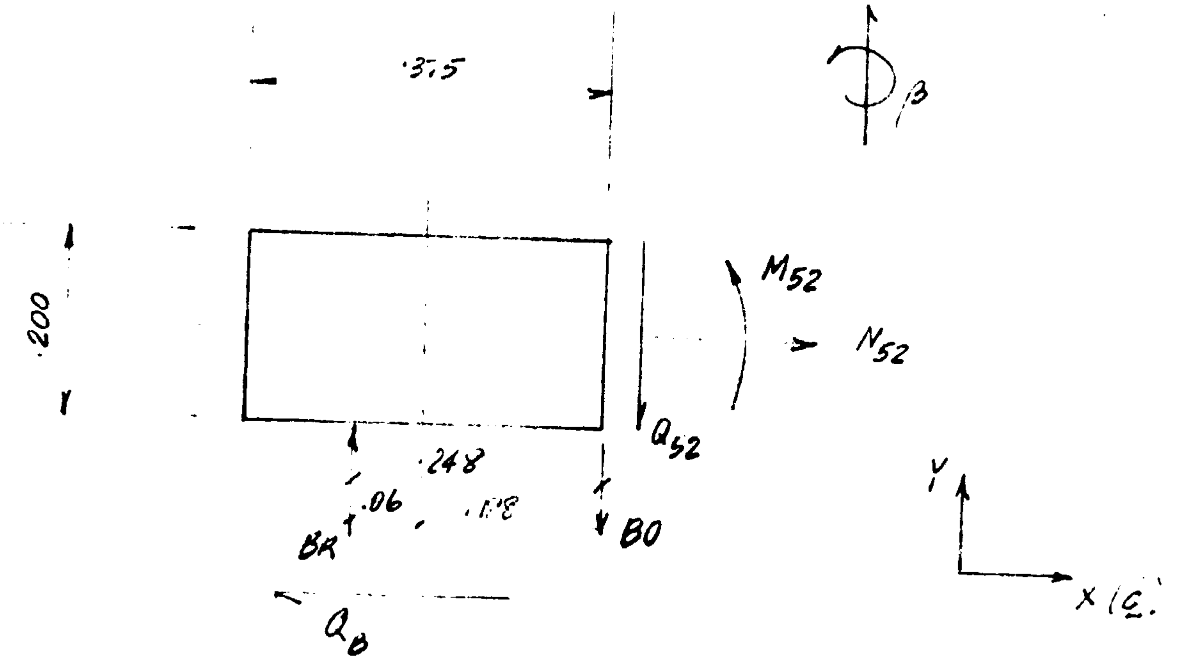
CASE NO. 1, CONFIGURATION NO. 1

RING NO. 1	LEFT INSIDE	LEFT OUTSIDE	RIGHT INSIDE	RIGHT OUTSIDE
DELTA	2.751362E-04	0.000000E+00	0.000000E+00	2.268337E-03
BETA	-1.107334E-02	0.000000E+00	0.000000E+00	-1.107334E-02
M	9.107653E+00	0.000000E+00	0.000000E+00	4.546861E+02
Q	2.283192E+02	0.000000E+00	0.000000E+00	-2.825901E+02
N	2.112067E+03	0.000000E+00	0.000000E+00	2.158241E+03

DEL-CG = -4.999976E-04 BETA-CG = -1.107334E-02

M-NET = -1.391161E+03 Q-NET = -3.608758E+02

BOLT LOADS



BO. : BOLT LOAD

BR : BEARING LOAD

Q_B : BOLT SHEAR

FROM ... II ...

M_{52} = 455 in lbs./in

Q_{52} = −289 lbs/in

N_{52} = 2160 lbs/in

δ_R = 2.27×10^{-3} in

β = -1.11×10^{-2} rads

$$\sum \overset{+}{\rightarrow} X = 0$$

$$-Q_B + N_{52} = 0$$

$$\therefore Q_B = N_{52} = 283 \text{ lb/in.}$$

$$+\uparrow Q_{NET} = BK - BO - Q_{52}$$

$$\delta = \frac{Q_{NET}\, \bar{R}^2}{EA}$$

$$= \frac{(BK - BO + 283)(5.0)^2}{(30 \times 10^6)(.375 \times .203)} = 2.27 \times 10^{-3}$$

$$\therefore BK - BO = -79 \quad lb$$

$$\overset{+}{\curvearrowleft} M_{NET} = -.06\, BK - .188\, BO - M_{52} - .1\, Q_B$$
$$- .188\, Q_{52}$$

$$\beta = \frac{M_{NET}\, \bar{R}^2}{EI}$$

$$= \frac{\left[-.06\, BK - .188\, BO + 455 - .1(\overset{.16}{2}83) - \overset{53}{.188}(283)\right](5.0)^2}{(30 \times 10^6)(8.79 \times 10^{-4})}$$

$$= -1.11 \times 10^{-2}$$

$$-.06\, BK - .188\, BO = -197.5 \quad lb$$

From (1) and (2)

$BR = 736.6$

$BO = 815.5$

BOLTS USED : 100° Close Tolerance Head & Shank, 160 ksi, Short thread.

NAS 1504-3

MS 21047 K2

24 —— 1/4 28 UNF 3A

$P_T = 4520$ lb. (Ultimate)

$$V_{All.} \text{ (Single Shear)} = 0.4\ V_{ALL} \text{ (Double Shear)}$$
$$= 0.4\ (9300)$$
$$= 3720 \text{ lb.}$$

$BO = 815.5$ lb/in.

$Q_B = 2160$ lb/in.

Using an inter-action formula (MIL-HDBK. 5 Figure 8.1.1.1.1)

$$\frac{X^3}{a^3} + \frac{Y^2}{b^2} = 1$$

X : Shear Load
Y : Tension Load
a : Mil-HDBK. 5, Shear Allowable
b : Mil-HDBK. 5, Tension Allowable

LOADS / BOLT

BOLT SPACING $= \frac{\pi(10)}{24} = 1.3$ in.

$\therefore$ LOADS / BOLT $= (2160)(1.3) = 2805$ lbs. shear

$(816)(1.3) = 1060$ lbs. tension

$$\left(\frac{2805}{3720}\right)^3 + \left(\frac{1060}{4520}\right)^2$$

$$= 0.43 + 0.13 = 0.56$$

$$\therefore MS = \frac{1}{0.56} - 1 = \underline{+0.78}$$

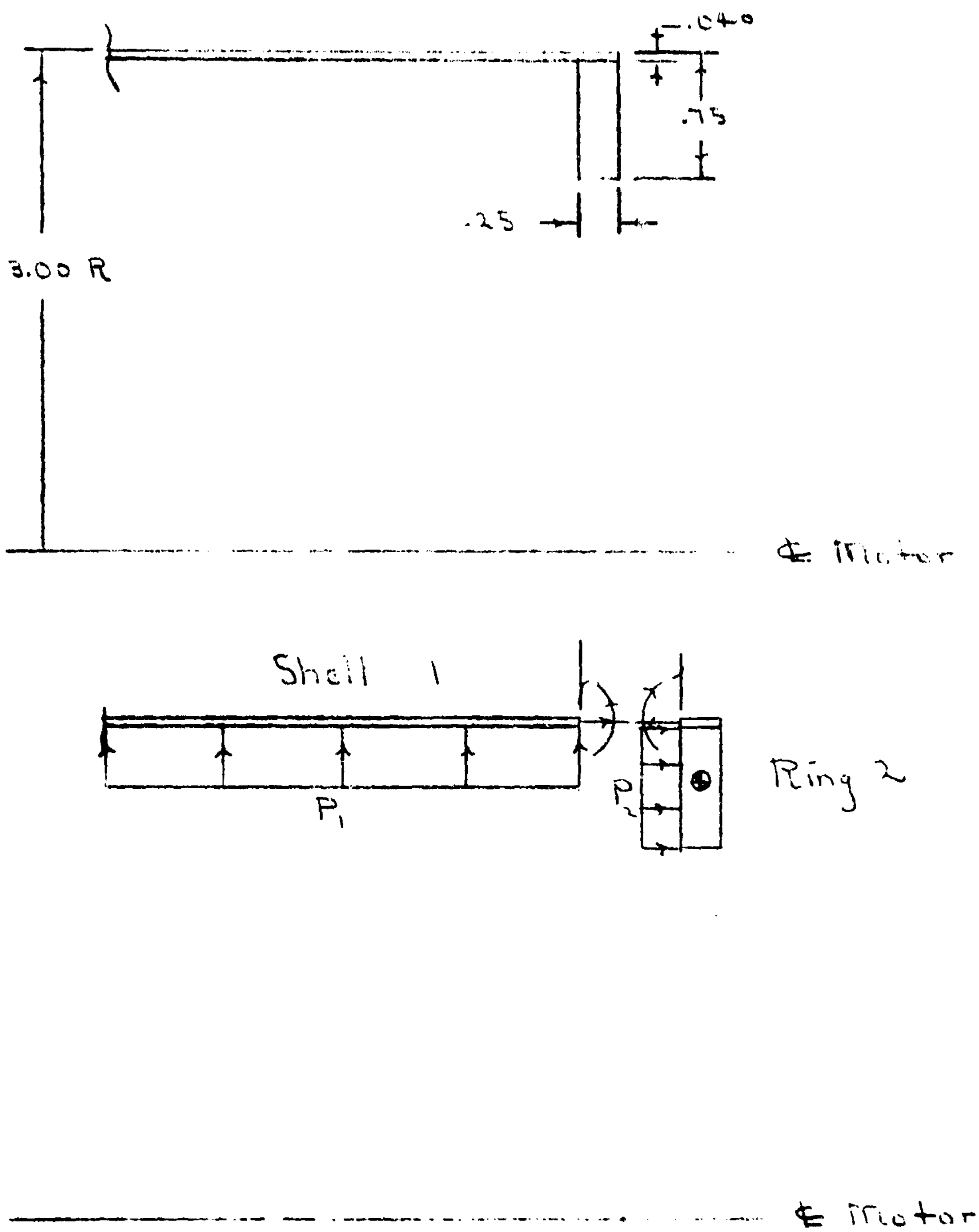


FIGURE 12

EXIT PLANE RING

$M = 10\,NS + 4\,NR + 5\,NRJ$

$M = 10\overset{10}{(1)} + 4\overset{4}{(1)} + 5\overset{5}{(1)} = 19$

NC, NS, 1, 1,

P_1 $910/2 = 455$

NR 1,

$F_x = -A\,p = -.71(910)\left(\frac{27.524}{11.622}\right) = -1530$ LB

$F_y = 0$

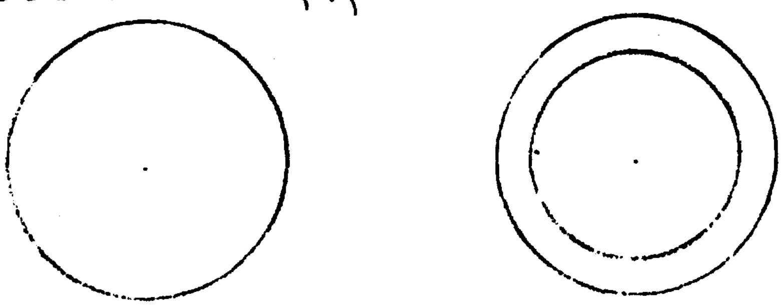
$M_{CG} = .020(1530) = 30.6 \approx 31$

S	R_1	R_2	ϕ
0	∞	2.98	90
1.50	∞	2.78	180

NJ 1,

NJ Sets 1, 2,

Location 1, 1,



$A = \frac{\pi}{4}(5.92)^2 = .78528(35.050) = 27.524 \text{ in}^2$

$P = pA = 910(27.524) = 25{,}047$ LB

$A = \frac{\pi}{4}\left[\overset{35.050}{(5.92)^2} - \overset{20.25}{(4.50)^2}\right] = .78528(14.80) = 11.6$--

$P_2 = \frac{25{,}047}{11.622} = 2155$ PSI

EXIT PLANE RING

Ring 1, Body 2

$$\begin{cases} RLI = 2.25 \\ PHILI = 90 \\ XLI = .095 \end{cases} \qquad \begin{cases} RLO = 2.98 \\ PHILO = 90 \\ XLO = .095 \end{cases}$$

$$\begin{cases} RRI = 0 \\ PHIRI = 0 \\ XRI = 0 \end{cases} \qquad \begin{cases} RRO = 0 \\ PHIRO = 0 \\ XRO = 0 \end{cases}$$

$R_{CG} = 2.625$

$A = .75(.19) = .1425 \text{ in}^2$

$I_{y-y} = \frac{.75}{12}(.19)^3 = .0004287 \text{ in}^4$

$E = 2.65 \times 10^7$ PSI

ATTACHMENT

COMPUTER PROGRAM LI-11-ZZZ

STRUCTURAL ANALYSIS OF

MULTIPLE SHELL/RING STRUCTURES

PAGES NOT FILMED ARE BLANK

STRUCTURAL ANALYSIS OF MULTIPLE SHELL/RING STRUCTURES UNITED TECHNOLOGY CENTER 6 OCT 1966

10 IN HYBRID,COMBUSTION CHAMBER,EXIT PLANE RING 6 OCT. 66

```
SHELL #1

SHELL UNIT ANALYSIS                                                        SHELL NO. 1,  CONFIGURATION NO. 1

INPUT IS:

        TAYLORS SERIES EXPANSIONS OF   5 TERMS ARE USED TO SOLVE THE DIFFERENTIAL EQUATIONS SIMULTANEOUSLY.
        THE    1.5000 INCH LONG SHELL SECTION IS DIVIDED INTO  50 SEGMENTS EACH OF WHICH IS  0.0300 INCHES LONG.

        MODULUS OF ELASTICITY, E =  2.65000P+07
        PUISSON S RATIO, MU =     0.3000

        MERIDIONALLY VARYING PARAMETER FUNCTIONS:


              RADIUS 1 =       1.0000P+10  1.0000P+10
                     S =       0.0000P+00  1.5000P+00


              RADIUS 2 =       2.9800P+00  2.9800P+00
                     S =       0.0000P+00  1.5000P+00


             THICKNESS =       4.0000P-02  4.0000P-02
                     S =       0.0000P+00  1.5000P+00


                   PHI =       9.0000P+01  9.0000P+01
                     S =       0.0000P+00  1.5000P+00
```

RING 1, BODY 2

RING UNIT ANALYSIS

RING NO. 1, CONFIGURATION NO. 1

INPUT IS:

	RADIUS, IN.	PHI, DEG.	X, IN.
LI	2.250	90.000	0.095
LU	2.980	90.000	0.095
RI	0.000	0.000	0.000
RU	0.000	0.000	0.000

RCG = 2.650 A = 0.143 IYY = 0.000 E = 2.650E+07

OUTPUT IS:

	QNET	MNET	AXIAL EQUIL
M-LI	0.0000E+00	-8.4906E-01	0.0000E+00
Q-	8.4906E-01	-8.0660E-02	-5.0223E-07
N-	1.8952E-07	-3.3962E-01	2.2500E+00
M-LU	0.0000E+00	-1.1245E+00	0.0000E+00
Q-	1.1245E+00	-1.0683E-01	5.3339E-09
N-	-2.0128E-09	3.7109E-01	2.9800E+00
M-RI	0.0000E+00	0.0000E+00	0.0000E+00
Q-	0.0000E+00	0.0000E+00	0.0000E+00
N-	0.0000E+00	0.0000E+00	0.0000E+00
M-RU	0.0000E+00	0.0000E+00	0.0000E+00
Q-	0.0000E+00	0.0000E+00	0.0000E+00
N-	0.0000E+00	0.0000E+00	0.0000E+00
FX	0.0000E+00	0.0000E+00	2.6500E+00
FY	1.0000E+00	0.0000E+00	0.0000E+00
MCG	0.0000E+00	1.0000E+00	0.0000E+00

DEL-CG = 1.[illegible]E-04 x QNET BETA-CG = [illegible]E-04 x MNET

SHELL/RING BOUNDRY CONDITIONS AND FORCES

CASE NO. 1, CONFIGURATION NO. 1

SHELL NO. 1

M-L = 0.0000D+00

Q-L = 0.0000D+00

N-L = 6.7800D+02

PRESSURE = 4.5500D+02

RING NO. 1

M-LI = 0.0000D+00

W-LI = 0.0000D+00

FX = -1.5300D+03 FY = 0.0000D+00 MCG = 3.1000D+01

RING 1,BODY 2

RING UNIT ANALYSIS

RING NO. 1, CONFIGURATION NO. 1

INPUT IS:

	RADIUS, IN.	PHI, DEG.	X, IN.
LI	2.250	90.000	0.095
LU	2.980	90.000	0.095
RI	0.000	0.000	0.000
RU	0.000	0.000	0.000

RCG = 2.650 A = 0.143 IYY = 0.000 E = 2.650D+07

OUTPUT IS:

	QNET	MNET	AXIAL EQUIL
M-LI	0.0000D+00	-8.4906D-01	0.0000D+00
Q-	8.4906D-01	-8.0660D-02	-5.0223D-07
N-	1.8952D-07	-3.3962D-01	2.2500D+00
M-LU	0.0000D+00	-1.1245D+00	0.0000D+00
Q-	1.1245D+00	-1.0683D-01	5.3339D-09
N-	-2.0128D-09	3.7109D-01	2.9800D+00
M-RI	0.0000D+00	0.0000D+00	0.0000D+00
Q-	0.0000D+00	0.0000D+00	0.0000D+00
N-	0.0000D+00	0.0000D+00	0.0000D+00
M-RU	0.0000D+00	0.0000D+00	0.0000D+00
Q-	0.0000D+00	0.0000D+00	0.0000D+00
N-	0.0000D+00	0.0000D+00	0.0000D+00
FX	0.0000D+00	0.0000D+00	2.6500D+00
FY	1.0000D+00	0.0000D+00	0.0000D+00
MCG	0.0000D+00	1.0000D+00	0.0000D+00

DEL-CG = 1.6596D-06 X Q-NET   BETA-CG = 6.1815D-04 X M-NET

SHELL/RING BOUNDARY CONDITIONS AND FORCES

CASE NO. 1, CONFIGURATION NO. 1

SHELL NO. 1

M-L = 0.0000D+00

Q-L = 0.0000D+00

N-L = 6.7800D+02

PRESSURE = 4.5500D+02

RING NO. 1

M-LI = 0.0000D+00

V-LI = 0.0000D+00

FX = -1.5300D+03 FY = 0.0000D+00 MCG = 3.1000D+01

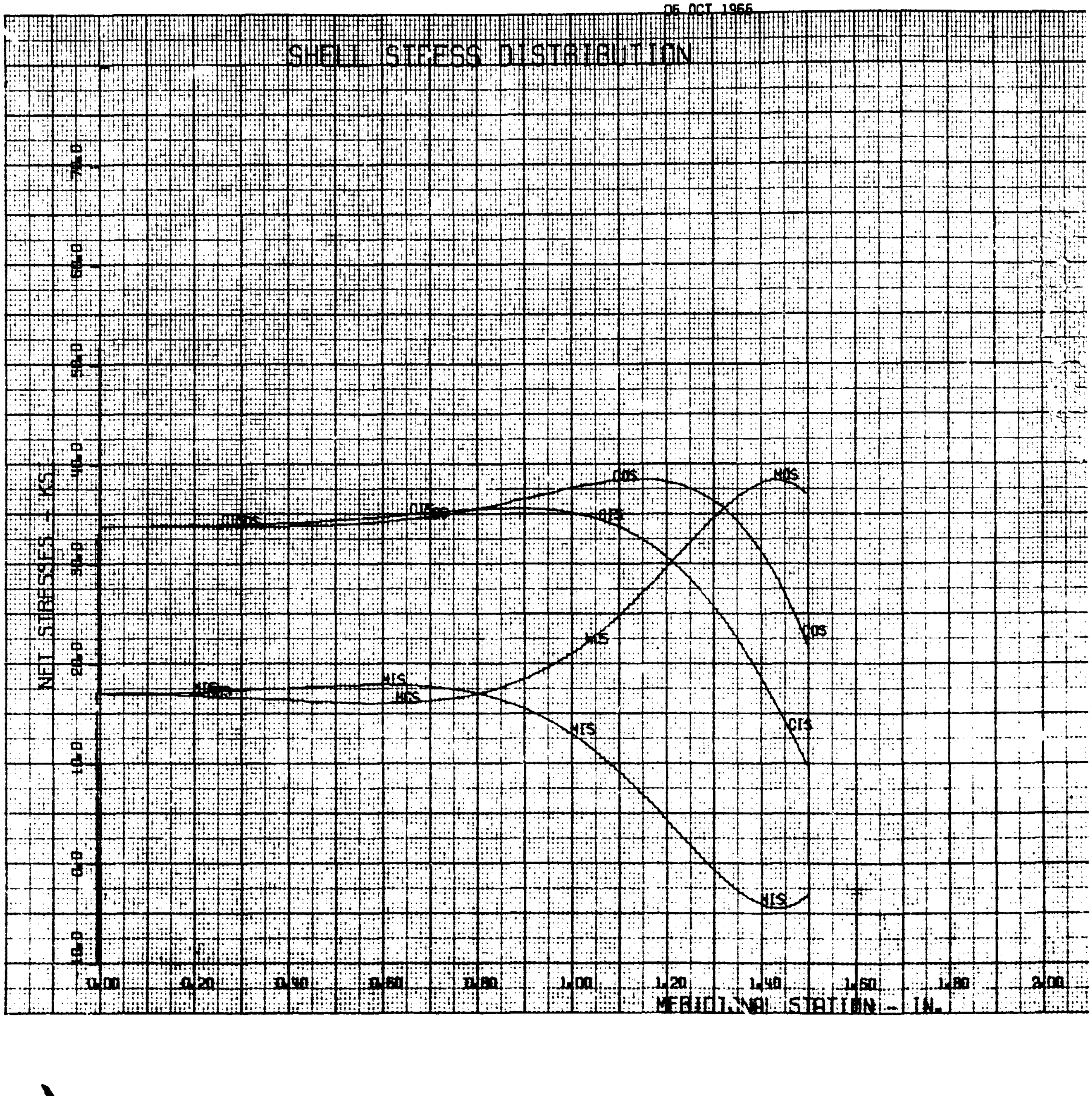
SHELL/RING DISCONTINUITY DEFORMATION AND FORCE SOLUTIONS CASE NO. 1, CONFIGURATION NO. 1

SHELL NO. 1	LEFT END	RIGHT END
DELTA	3.219687D-03	1.190480D-03
BETA	1.987267D-05	-1.224567D-02
M	0.000000D+00	-5.337419D+00
Q	0.000000D+00	1.297866D+01
N	6.780000D+02	6.780002D+02

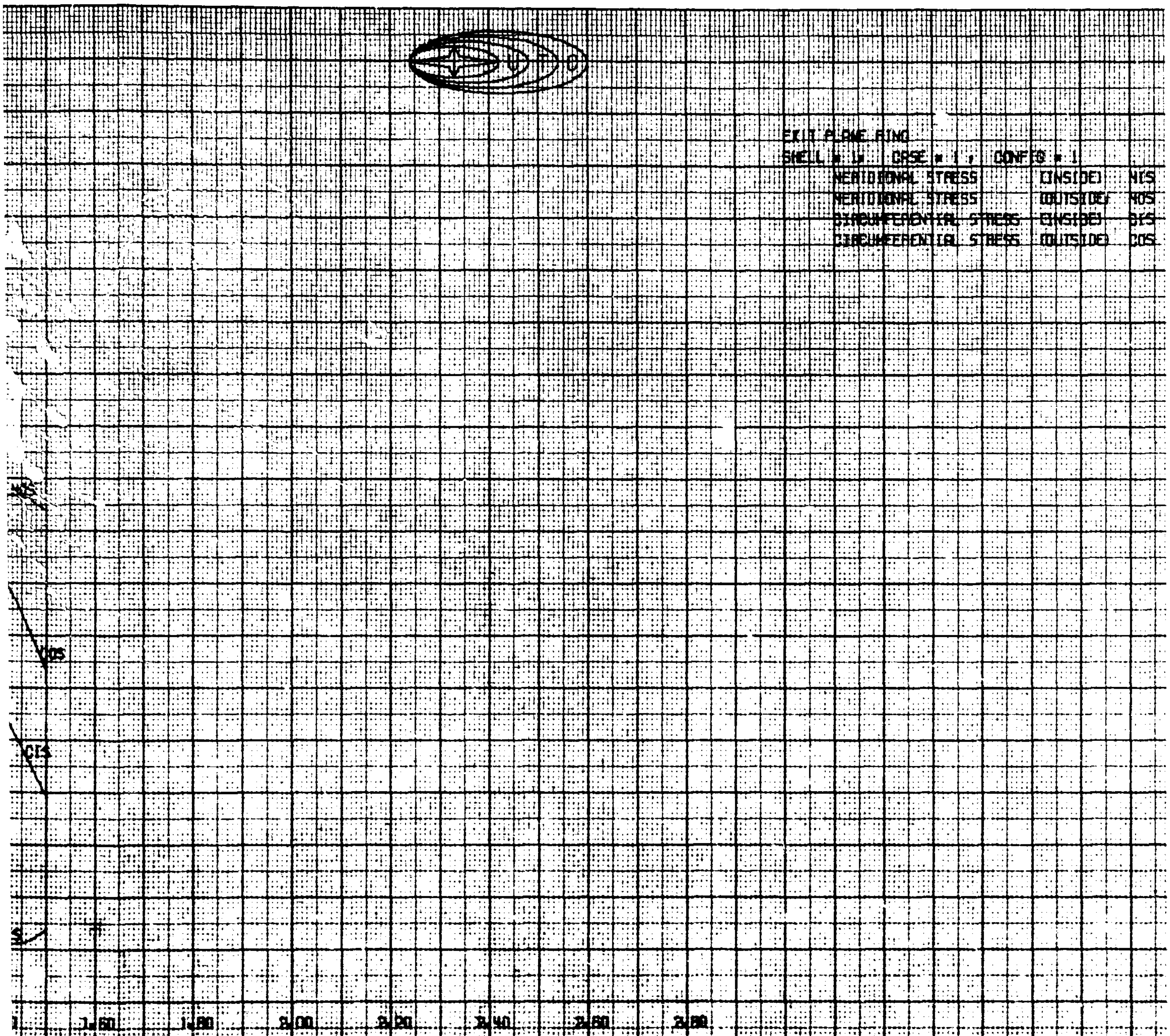
RING NO. 1	LEFT INSIDE	LEFT OUTSIDE	RIGHT INSIDE	RIGHT OUTSIDE
DELTA	1.190480D-03	1.190480D-03	0.000000D+00	0.000000D+00
BETA	-1.224567D-02	-1.224567D-02	0.000000D+00	0.000000D+00
M	0.000000D+00	-5.337419D+00	0.000000D+00	0.000000D+00
Q	0.000000D+00	1.297866D+01	0.000000D+00	0.000000D+00
N	9.040264D+02	6.780002D+02	0.000000D+00	0.000000D+00

DEL-CG = 2.714164D-05 BETA-CG = -1.224567D-02

M-NET = -1.981026D+01 Q-NET = 1.459504D+01



06 OCT 1966
SHELL STRESS DISTRIBUTION
NET STRESSES - KSI
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
-10.0
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
2.00
MERIDIONAL STATION - IN.
COS
MOS
CIS
MIS


EXIT PLANE RING
SHELL # 1, CASE # 1, CONFIG # 1
MERIDIONAL STRESS (INSIDE) MIS
MERIDIONAL STRESS (OUTSIDE) MOS
CIRCUMFERENTIAL STRESS (INSIDE) CIS
CIRCUMFERENTIAL STRESS (OUTSIDE) COS
MOS
COS
CIS
1.60
1.80
2.00
2.20
2.40
2.60
2.80
STATION - IN.

COMPUTER PROGRAM LI-11-ZZZ

"STRUCTURAL ANALYSIS OF MULTIPLE SHELL/RING STRUCTURES"

Computer program LI-11-ZZZ performs a complete structural analysis of multiple shell/ring structures. The input to the computer program consists of the multiple shell/ring structure geometry description, the shell pressures and ring loads, and the shell/ring boundary or edge conditions. The computer code determines the deformation equations for each shell and ring body, enforces compatibility of deformations and forces at each juncture, and solves the resulting matrix for the redundant deformations and forces at each juncture of the structure. The stress and deflection distributions are then determined for each shell body and output in tabular and graphical form. Additionally, bolt loads are determined for each bolted flange of the structure.

The program will accept multiple cases of shell pressures, ring forces, and boundary conditions for a given configuration.

The following existing UTC computer programs were incorporated as procedures in LI-11-ZZZ.

1. LI-13-ZZZ, Thin Shell Unit Analysis
2. LI-14-ZZZ, Thin Shell Stress Distribution
3. CROSIM procedure to solve NXN linear simultaneous equations.

Additionally, the following procedures were written and programmed for LI-11-ZZZ:

1. Ring Unit Analysis
2. Bolt Loads

The attached pages present the program input, the input for a sample case, and the shell/ring geometry, deformation, and force descriptions.

COMPUTER PROGRAM LI112ZZ

"STRUCTURAL ANALYSIS OF MULTIPLE SHELL/RING STRUCTURES"

— INPUT —

FORMAT: FREE FIELD IN COLUMNS 1 TO 80 EXCEPT TITLE CARDS AND CONTROL CARDS.

1. TITLE CARDS: $1 \leq n \leq 20$ with 9 in Column 73 of last card. Title in Columns 1 to 72.

2. MATRIX SIZE CARD: M,

   WHERE:

   M = 10 NS + 4 NR + 5 NRJ

   = Matrix Size $\leq$ 108

   NS = Number of Shells

   NR = Number of Rings

   NRJ = Total number of ring junctures (all rings combined)

3. NUMBER CASES/SHELLS CARD: NC, NS,

   WHERE:

   NC = number of cases, $1 \leq NC \leq 10$ (a case is defined as a given set of shell pressures, ring forces, and shell/ring boundary conditions for a fixed configuration)

   NS = Number of Shells

4. SHELL PRESSURE CARDS:

   P_1, P_2, P_3, ----, P_{NS},

   NS shell pressures for each case, starting each case on a new card. Use as many cards for each case as necessary.

5. NUMBER RINGS/RING FORCES CARDS:

   Card 1: NR,

   Cards 2 to n: FX, FY, MCG, ------,

   NR sets of ring forces (FX, FY, MCG) for each case. Repeat cards 2 to n for each case starting each case on a new card. Use as many cards for each case as necessary.

6. SHELL UNIT ANALYSIS

   Card 1: title card, Columns 1-78

   Card 2: "YES" in Columns 1-3 if influence coefficients are input, else "NO" in Columns 1 and 2.

   If "YES" next five cards with influence coefficients in following order:

	M-L	Q-L	M-R	Q-R	N-R	P
DEL-L:						
BETA-L:						
DEL-R:		See LI11ZZZ output for typical set				
BETA-R:						
N-L:						

If "NO" input the following shell parameters:

Card 3: Shell length, Poisson's ratio , Young's Modulus,

Card 4: No. of segments, Taylor Series,

Cards 5 to n: Specify the following FGEN'S

Radius 1 vs. S

Radius 2 vs. S

Thickness vs. S

Angle PHI vs. S

The FGEN'S are read in as follows:

Card 1: Header card, i.e., Radius 1 vs. S

Cards 2 to n: No. of pairs, S1, Value 1, S2, Value 2, etc.

This completes the shell unit analysis input, repeat for each shell body for NS sets of input. The input for each shell body must be ordered the same as the shell body numbers.

7. RING UNIT ANALYSIS

Card 1: Title Card, Columns 1-78.

Cards 2 to n: The following cards list the ring geometry. Use as many cards as needed. Input all values even if zero. The parameters are: RLI, PHILI, XLI, RLO, PHILO, XLO, RRI, PHIRI, XRI, RRO, PHIRO, XRO, RCG, A, IYY, E

This completes the ring unit analysis input, repeat for each ring body for NR sets of input. The ring bodies must be ordered the same as the ring body numbers and stacked behind the shell unit analysis input.

8. JUNCTURE CARDS

The juncture cards specify the multiple shell/ring junctures, The juncture cards are as follows.

Card 1: Total number of junctures, NJ,

Card 2: NJ sets of i, j, juncture coordinates.

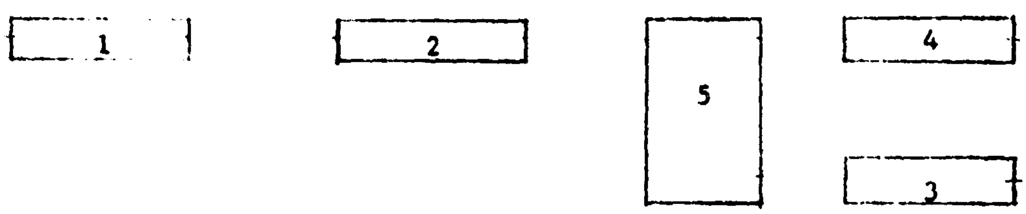
WHERE: i, j, = Body numbers (either shell or ring) of bodies forming the juncture.

Card 3: Location of juncture for each body of Card 1 using the following code:

Shells: 0=left
1=right

Rings: 0=left inside
1=left outside
2=right inside
3=right outside

EXAMPLE OF JUNCTURE CARDS



Card 1: 4,

Card 2: 1, 2, 2, 5, 5, 3, 5, 4,

Card 3: 1, 0, 1, 1, 2, 0, 3, 0,

9. BOUNDARY CONDITION CARDS

Each free edge must have a set of two boundary conditions specified. NE sets of boundary conditions must be specified for each shell/ring structure. Where NE = number of free edges. The following sets of boundary conditions are permissible.

1. Delta and Beta
2. M and Q
3. Delta and M
4. Beta and Q

Additionally each shell/ring structure must have (NE-1) Meridional forces (N_L or N_R) specified (this assumes the structure has a single load path). The meridional forces may be specified at the edges or junctures.

The total number of boundary conditions to be specified for each case is then 3NE-1. The boundary condition cards are as follows.

Card 1: Number of boundary conditions (B.C.) specified.

Card 2: Body number (either shell or ring) for each B.C. in increasing order.

Card 3: Location on body for each B.C. using following code.

Shells: 0 = left
1 = right

Rings: 0 = left inside
1 = left outside
2 = right inside
3 = right outside

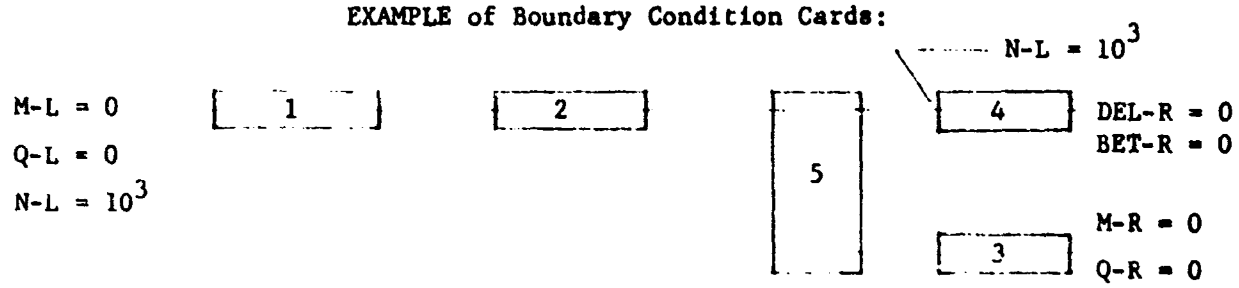
Card 4: B.C. Number for each B.C. using following code:

1 = DELTA
2 = BETA
3 = M
4 = Q
5 = N

Card 5: Value for each B.C., use as many cards as required.

<u>Repeat Cards 1 through 5 for each case.</u>

EXAMPLE of Boundary Condition Cards:



Card 1: 8,

Card 2: 1, 1, 1, 3, 3, 4, 4, 4,

Card 3: 0, 0, 0, 1, 1, 0, 1, 1,

Card 4: 3, 4, 5, 3, 4, 5, 1, 2,

Card 5: 0, 0, @3, 0, 0, @3, 0, 0,

10. SHELL STRESS DISTRIBUTION

Card 1: "YES" in Columns 1 to 3 if stress distributions are to be determined for any of the shell bodies, else "NO" in Columns 1 and 2.

If "YES" input the following

Card 2: NSS, S_1, S_2, - - - - , S_n,

WHERE: NSS = total number of shells for stress distribution.

S_1, S_2 -- , S_n, = Shell number of each shell for stress distribution. $1 \leq NSS \leq NS$

Cards 3 to n: INPUT FOR FIRST SHELL BODY:

Card 3: Title Card, Columns 1 to 78.

Card 4: Shell length, Poisson's ratio, Young's Modulus, Print out interval NPR,

NOTE: NPR $\geq$ 1

Card 5: Number of segments, Taylor series, plot length.

NOTE: If plots are not desired let plot length = 0.

Cards 6 to n: Specify the following FGEN'S.

Radius 1 vs. S

Radius 2 vs. S

Thickness vs. S

Angle PHI vs. S

The FGEN'S are read in as follows:

Card 1: Header card, i.e., Radius 1 vs. S

Card 2 to n: Number of pairs, S1, value 1, S2, value 2, etc.

Card n + 1: NCS, C1, C2, ---, C_n,

WHERE: NCS = total number of cases for stress distribution,

$1 \leq NCS \leq NC$

C1, C2, --, Cn, = Case numbers.

Card n + 2 to n + 2 + NCS: Plot title card for each case if plot length > 0. Omit if plot length = 0.

This completes the shell stress distribution input, repeat cards 3 to n + 2 + NCS for each shell body for NSS sets of input. The shell bodies must be ordered as indicated on card 2.

If card 1 "NO" go to Bolt Loads.

11. BOLT LOADS

Card 1: "YES" in columns 1 to 3 if bolt loads are to be determined for any of the ring bodies, else "NO' in columns 1 and 2.

Card 2: NRB, R_1, R_2, ---, Rn,

WHERE: NRB = Total number of rings for bolt load calculations. $1 \leq NRB \leq NR$

R_1, R_2, -- , R_n, = Ring numbers for each ring that requires bolt load calculations.

Cards 3 to n: INPUT FOR FIRST RING BODY:

Card 3: Title card, Columns 1 to 78

Card 3 to n: The following cards list the ring (left flange of the total ring) geometry. Use as many cards as needed. Input all values even if zero. The parameters are:

XLO, XLI, RB, YBO, YBI, XB, RLO, RLI, A, PHILO, PHILI, IYY, E, N, RCG,

WHERE N = total number of bolts

Card n + 1: NCB, C_1, C_2, --- , C_n,

WHERE: NCB = total number of cases for bolt load calculations, $1 \leq NCB \leq NC$

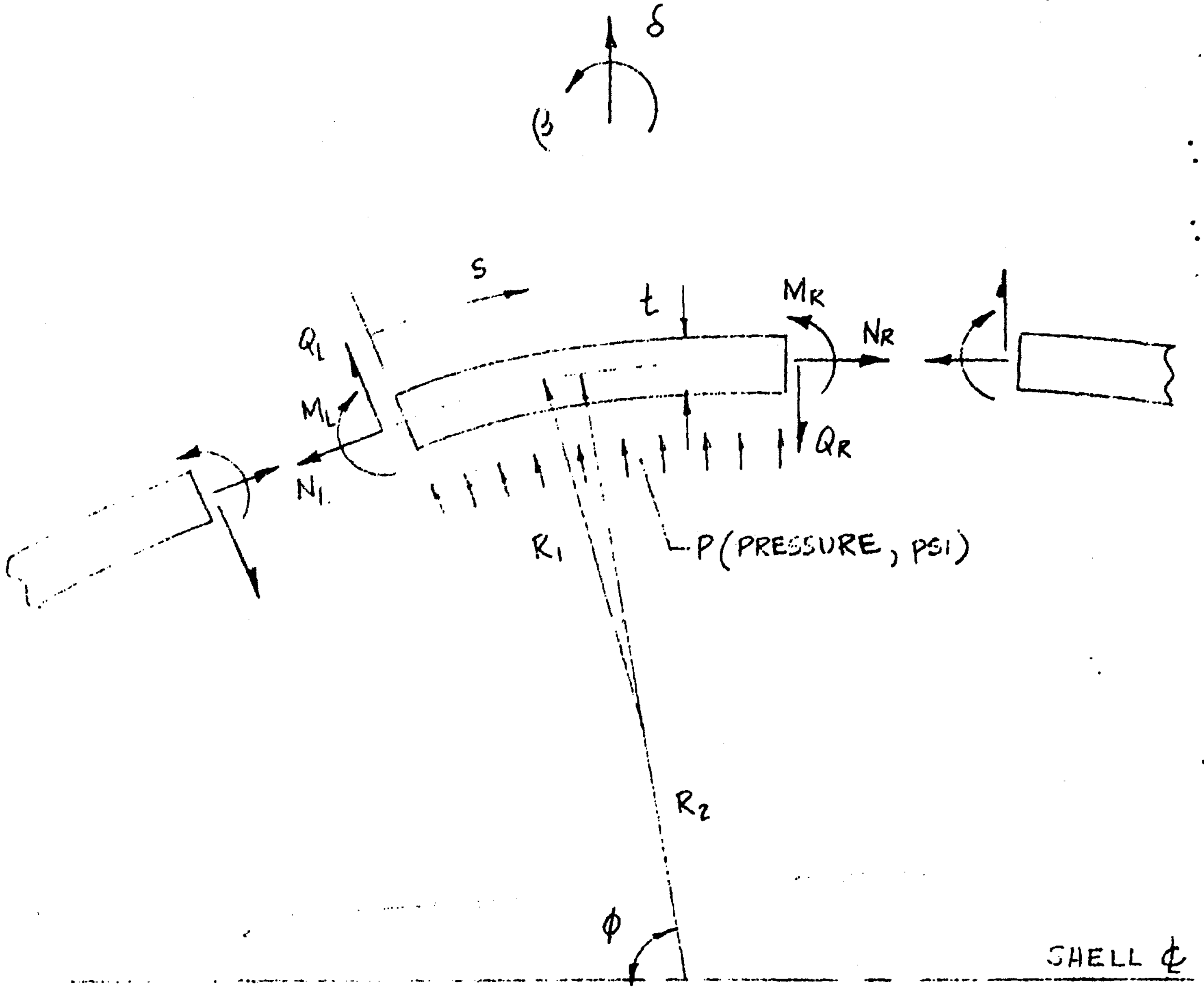
C_1, C_2, --, C_n, = Case numbers

Card n + 2: F_X, F_Y, MCG,

NCB sets of ring force cards (FX, FY, MCG), use as many cards as needed. Begin each set on a new card

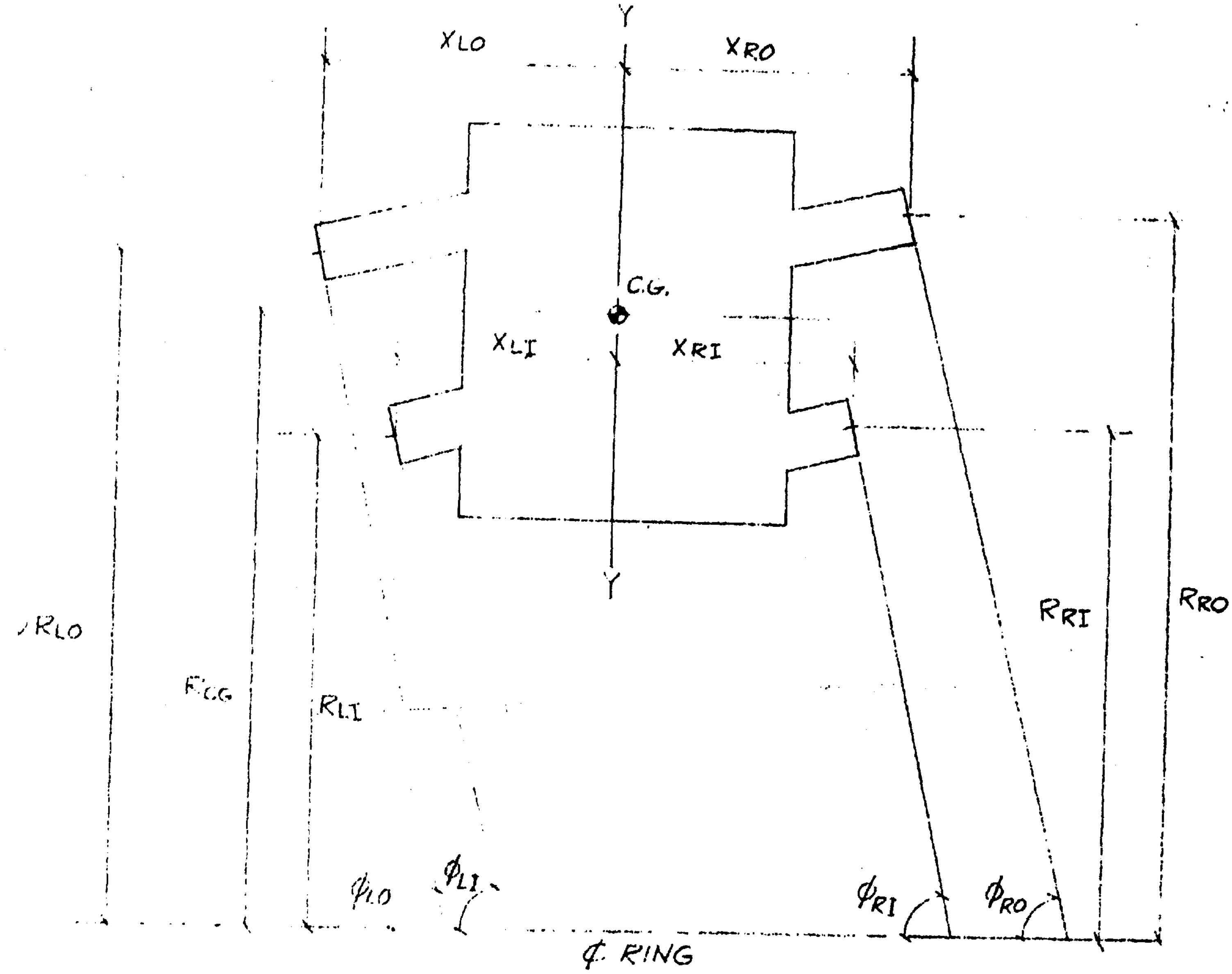
This completes the bolt load input, repeat Cards 3 to n + 2 for each ring body for NRB sets of input. The ring bodies must be ordered as indicated on card 2.

IF Card 1 "NO", THAT'S ALL.



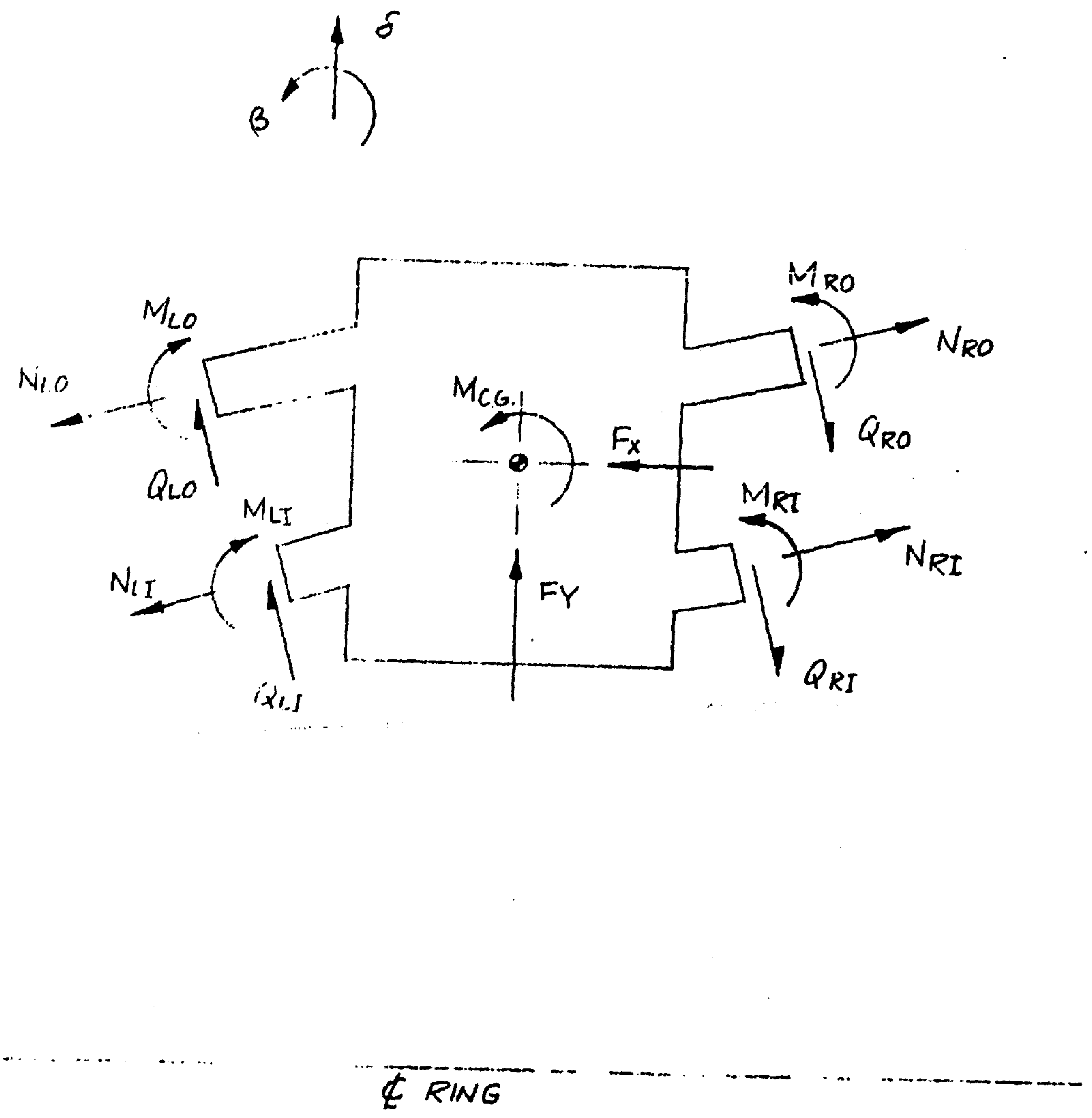
GEOMETRY AND FORCES FOR
TYPICAL SHELL BODY

NOTE: ALL DIMENSION IN INCHES,
ANGLES IN DEGREES.
N, Q IN lb/IN.
M IN IN-lb/IN
S IN INCHES
β IN RADIANS



RING GEOMETRY

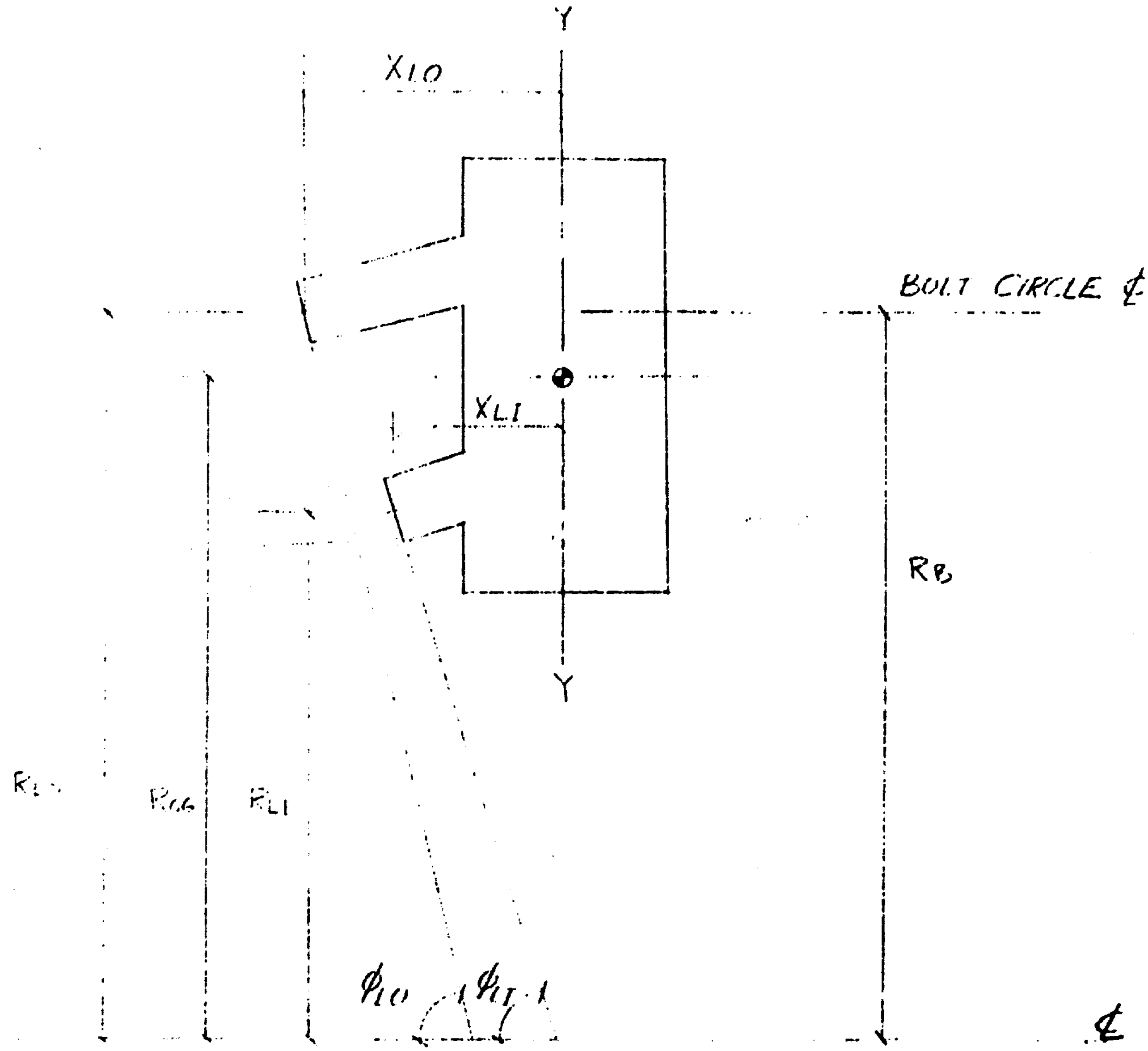
NOTE: ALL DIMENSIONS IN INCHES,
ANGLES IN DEGREES
A = RING AREA, IN^2
I_{YY} = RING MOMENT OF INERTIA ABOUT Y-Y AXIS, IN^4
E = RING MODULUS OF ELASTICITY, PSI



RING FORCES

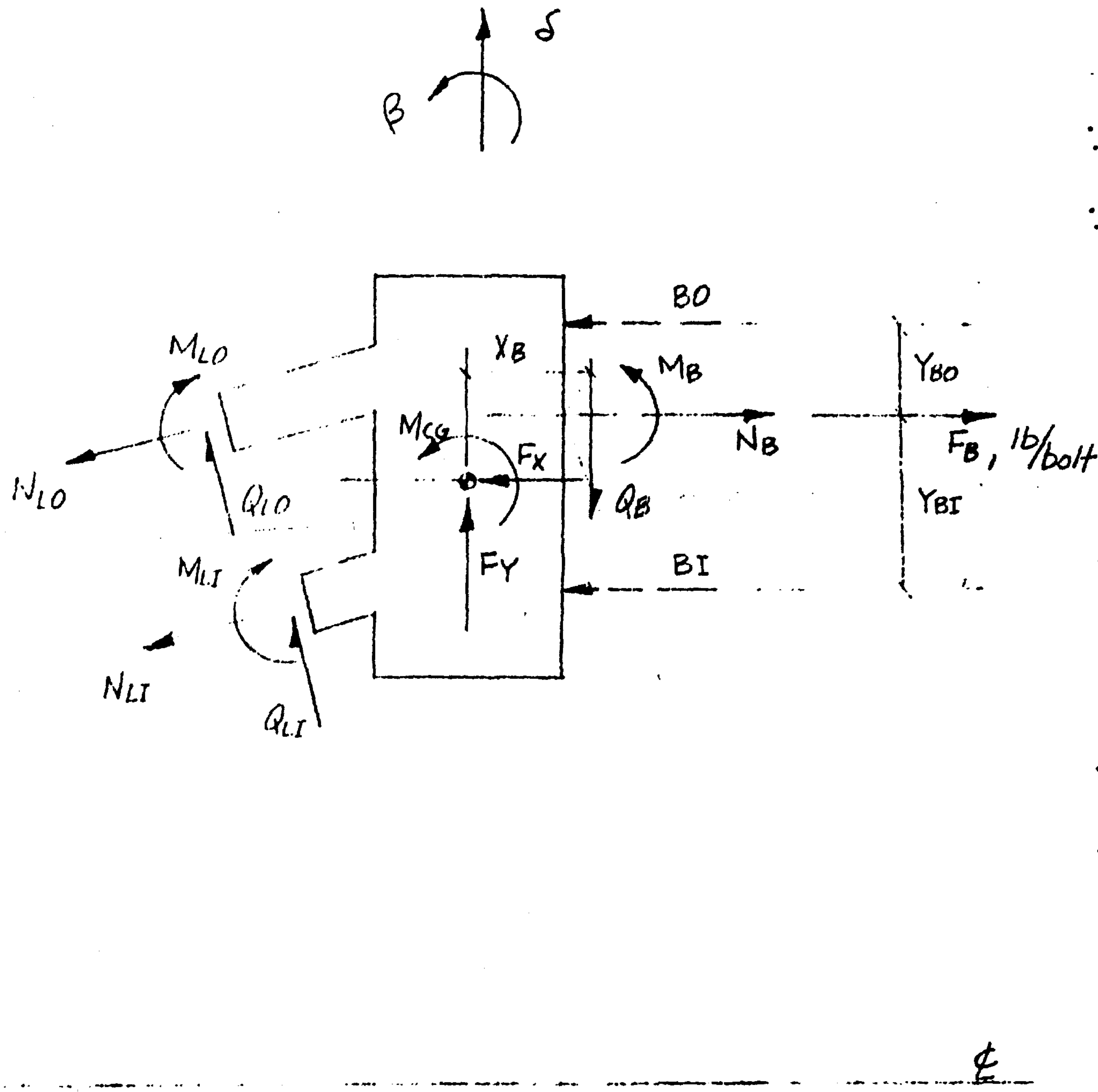
NOTE : N, Q, FX, FY IN lb/IN
M IN IN-lb/IN
δ IN INCHES
β IN RADIANS

FX, FY & MC.G ARE RESULTANT FORCES REFERENCED TO RING C.G. (DUE TO PRESSURE AND EXTERNAL LOADS).



BOLTED FLANGE GEOMETRY

NOTE: ALL DIMENSIONS IN INCHES,
ANGLES IN DEGREES
A = RING AREA, IN^2
I_Y = RING MOMENT OF INERTIA ABOUT Y-Y AXIS, IN^4
E = RING MODULUS OF ELASTICITY, PSI
N = NUMBER OF BOLTS



BOLTED FLANGE FORCES

NOTE: N, Q, B, F_X, F_Y IN lb/IN
M IN IN-lb/IN
F_B IN lb/bolt
δ IN INCHES
β IN RADIANS
F_X, F_Y & M_{CG} ARE RESULTANT FORCES REFERRED TO RING C.G. (DUE TO PRESSURE AND EXTERNAL LOADS)

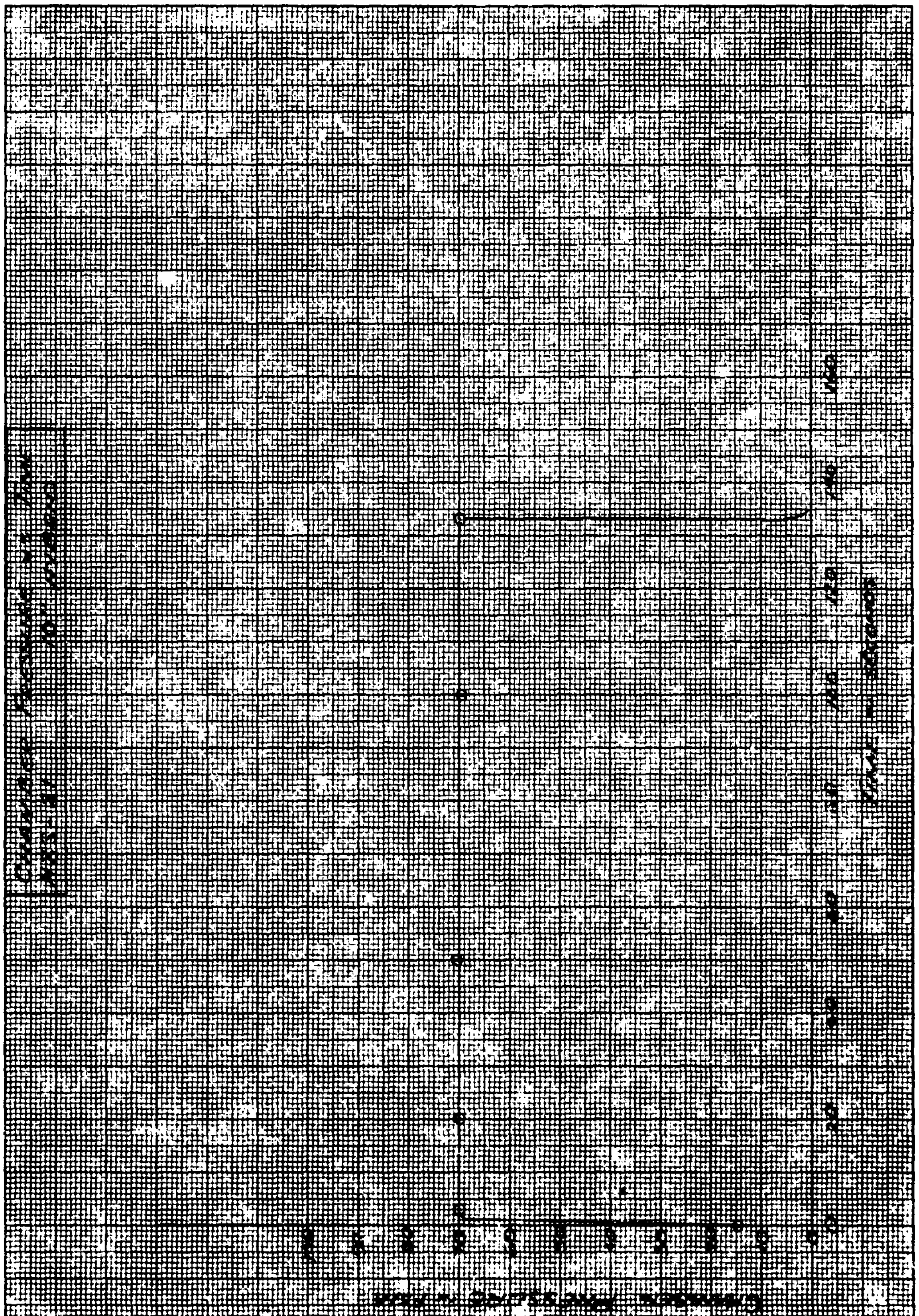
APPENDIX II

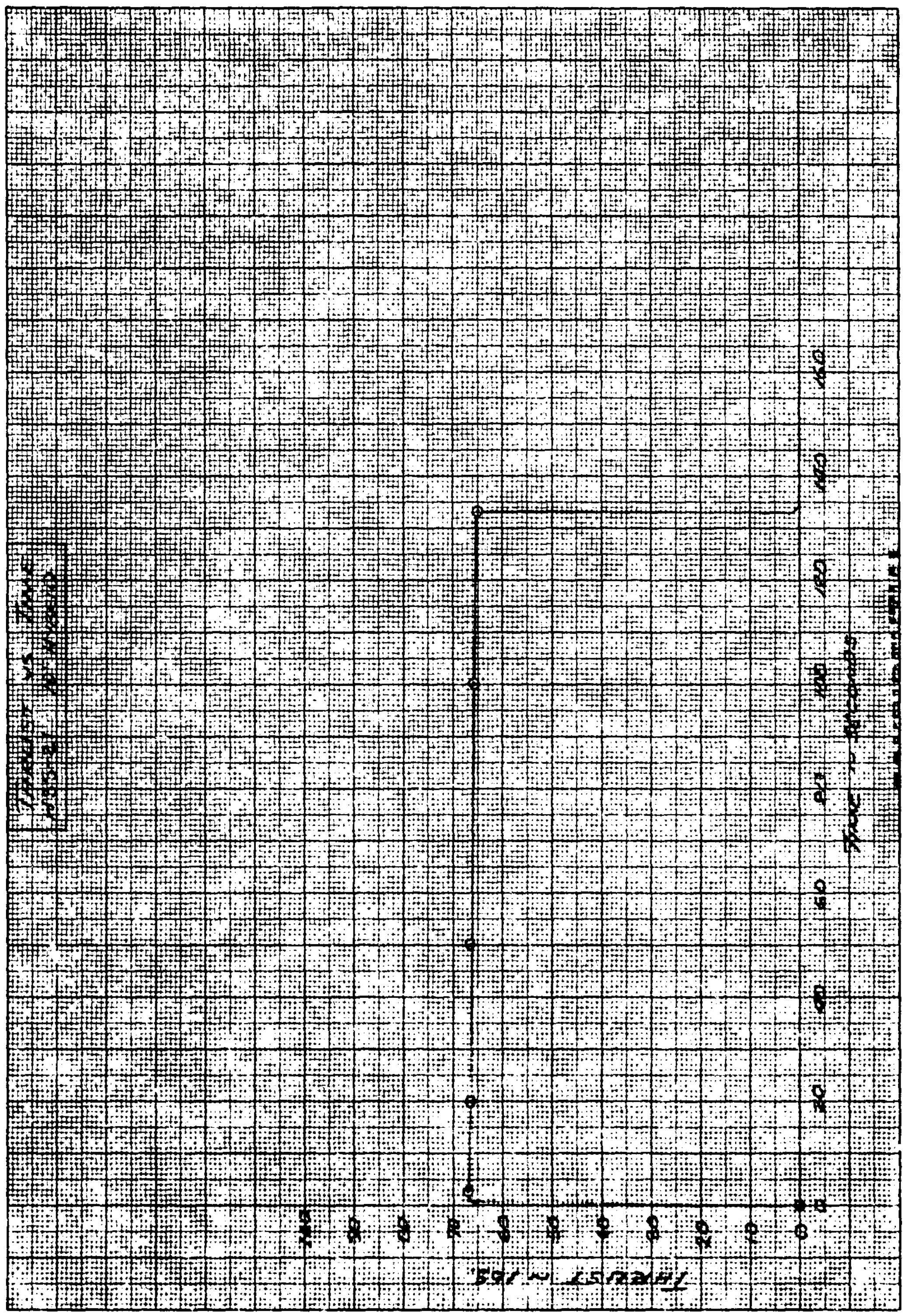
DETAILED TEST RESULTS

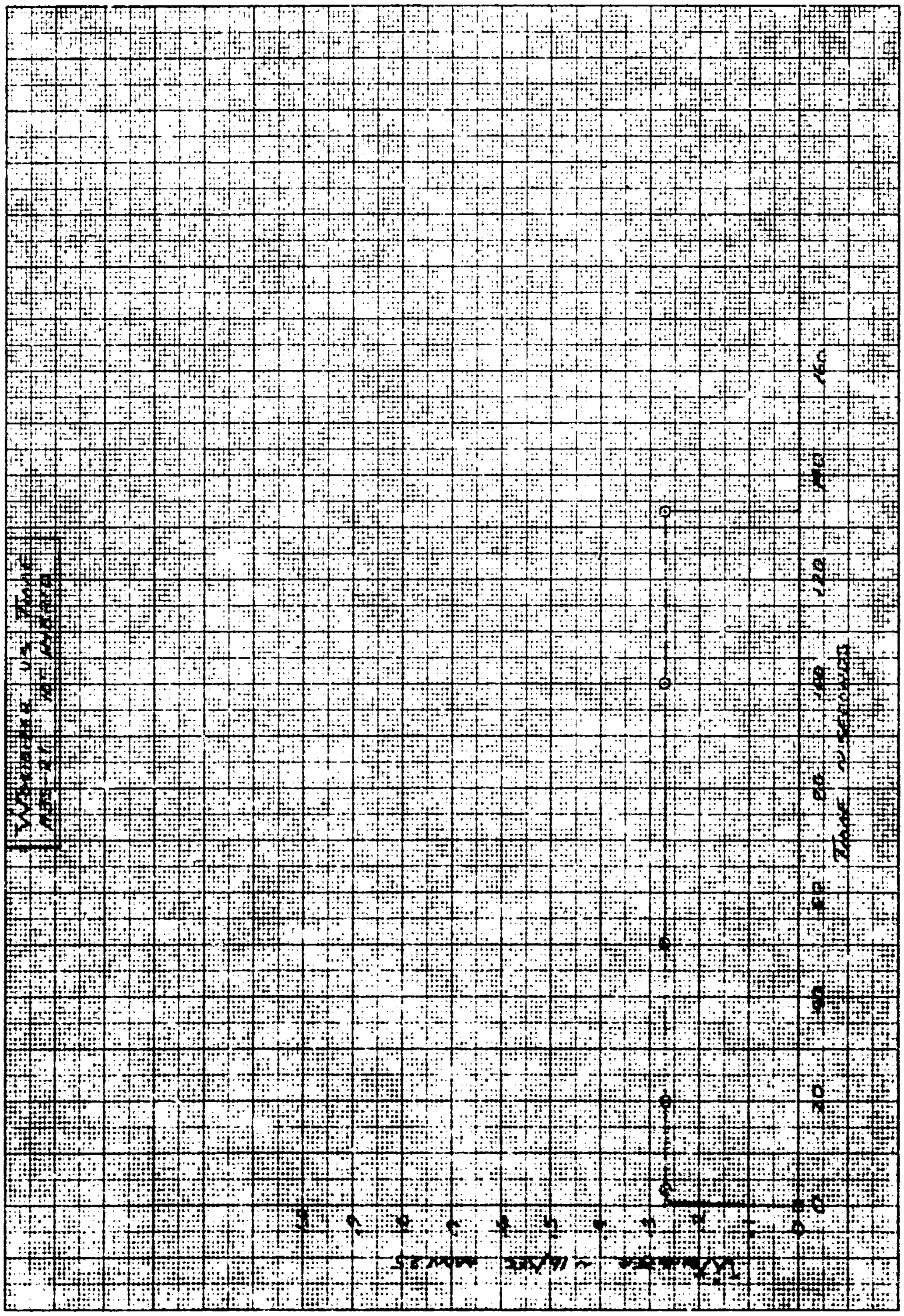
TABLE II-1

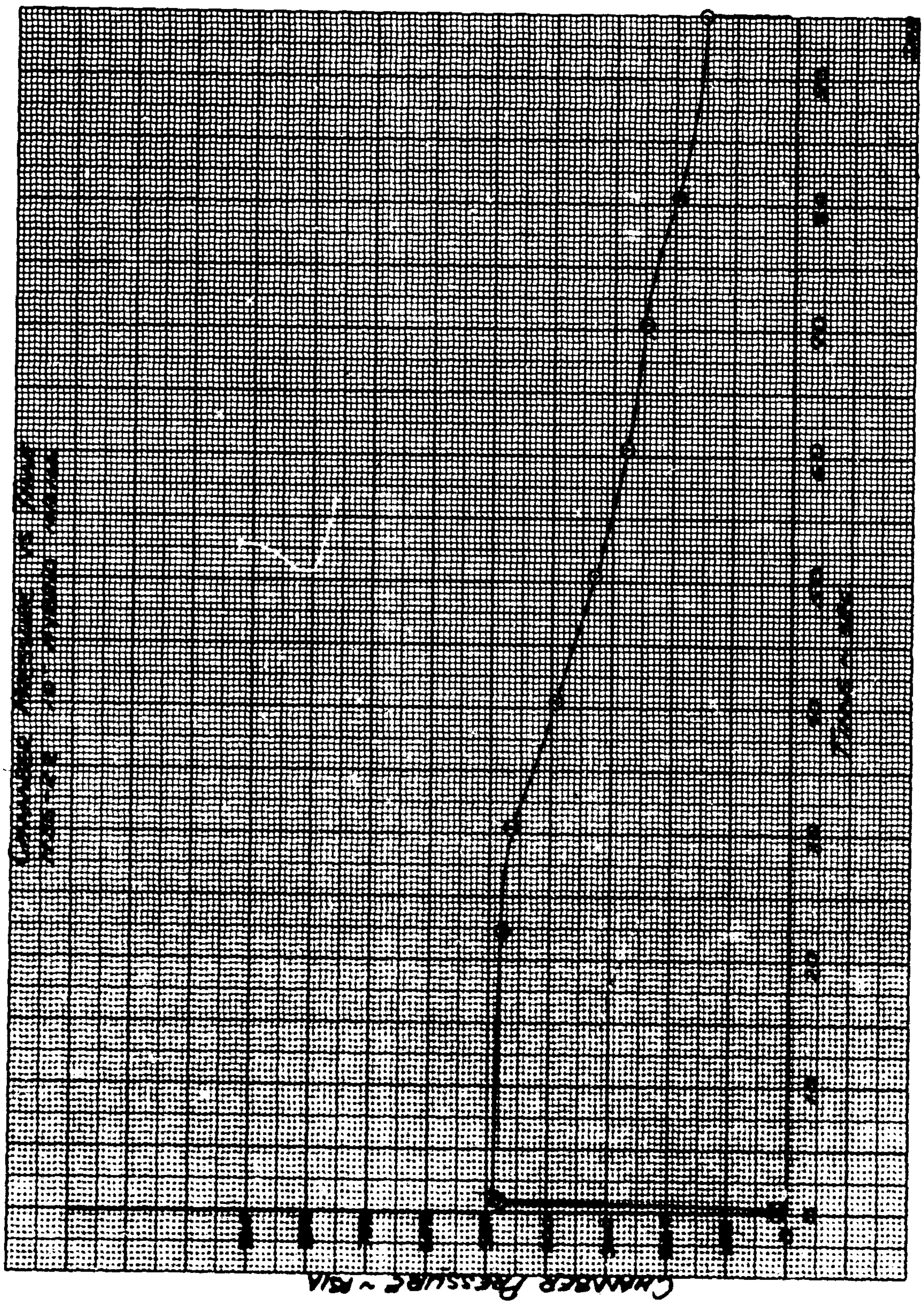
(U) FUEL CONSUMPTION SUMMARY

Test No.	Weight of Fuel Expended, lb
H3S-10	66.97
H3S-13	27.00
H3S-14	56.20
H3S-15	38.50
H3S-16	71.68
H3S-18	24.22
H3S-19	58.30
H3S-20	40.9
H3S-21	40.9
H3S-22	57.3
H3S-24	2.671
H3S-25	62.6
H3S-27	39.6
H3S-31	57.53
H3S-32	93.0
H3S-33	89.0
H3S-34	8.3
H3S-35	64.4
H3S-37	87.0
H3S-38	95.5
H3S-39	1.603









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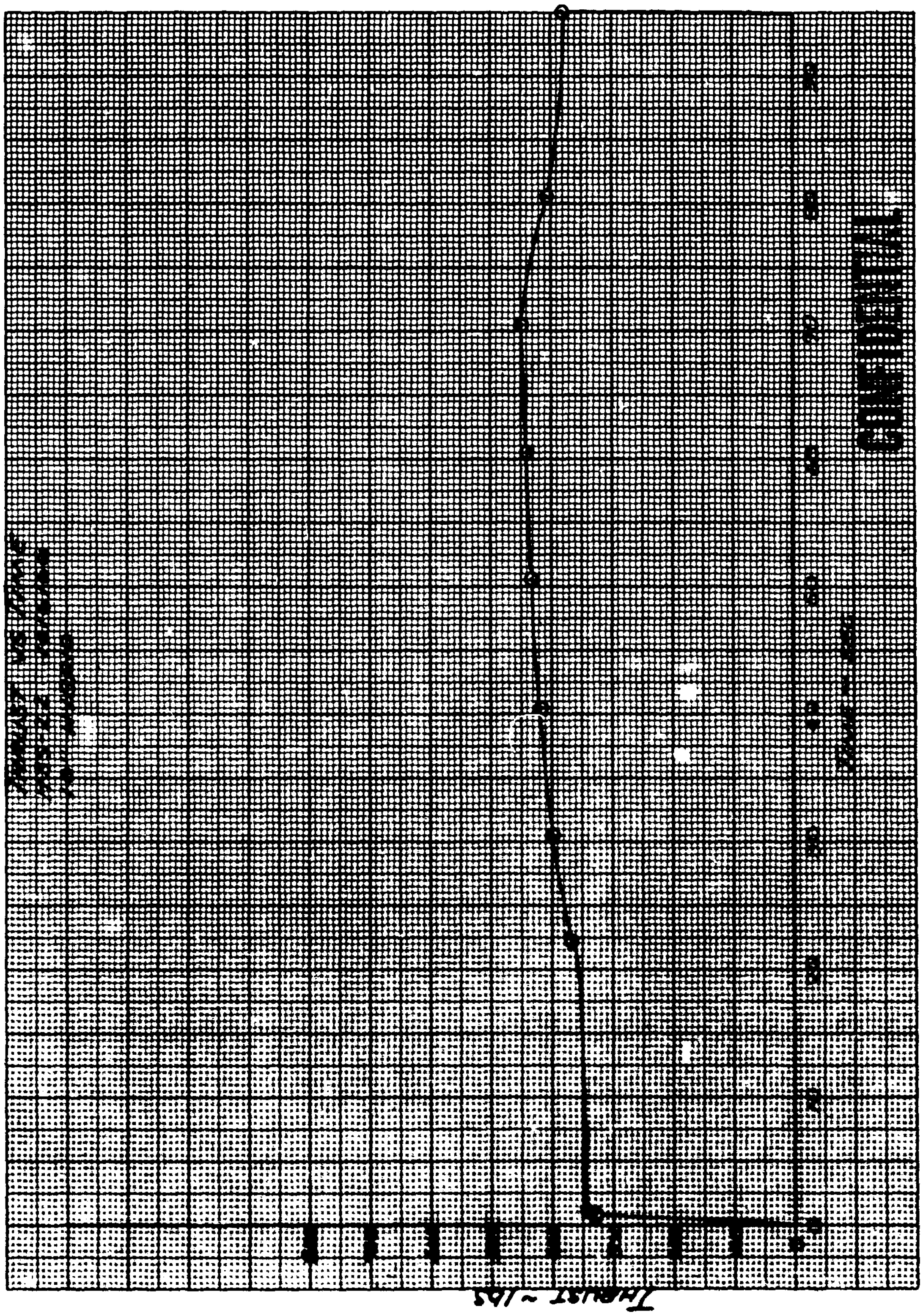
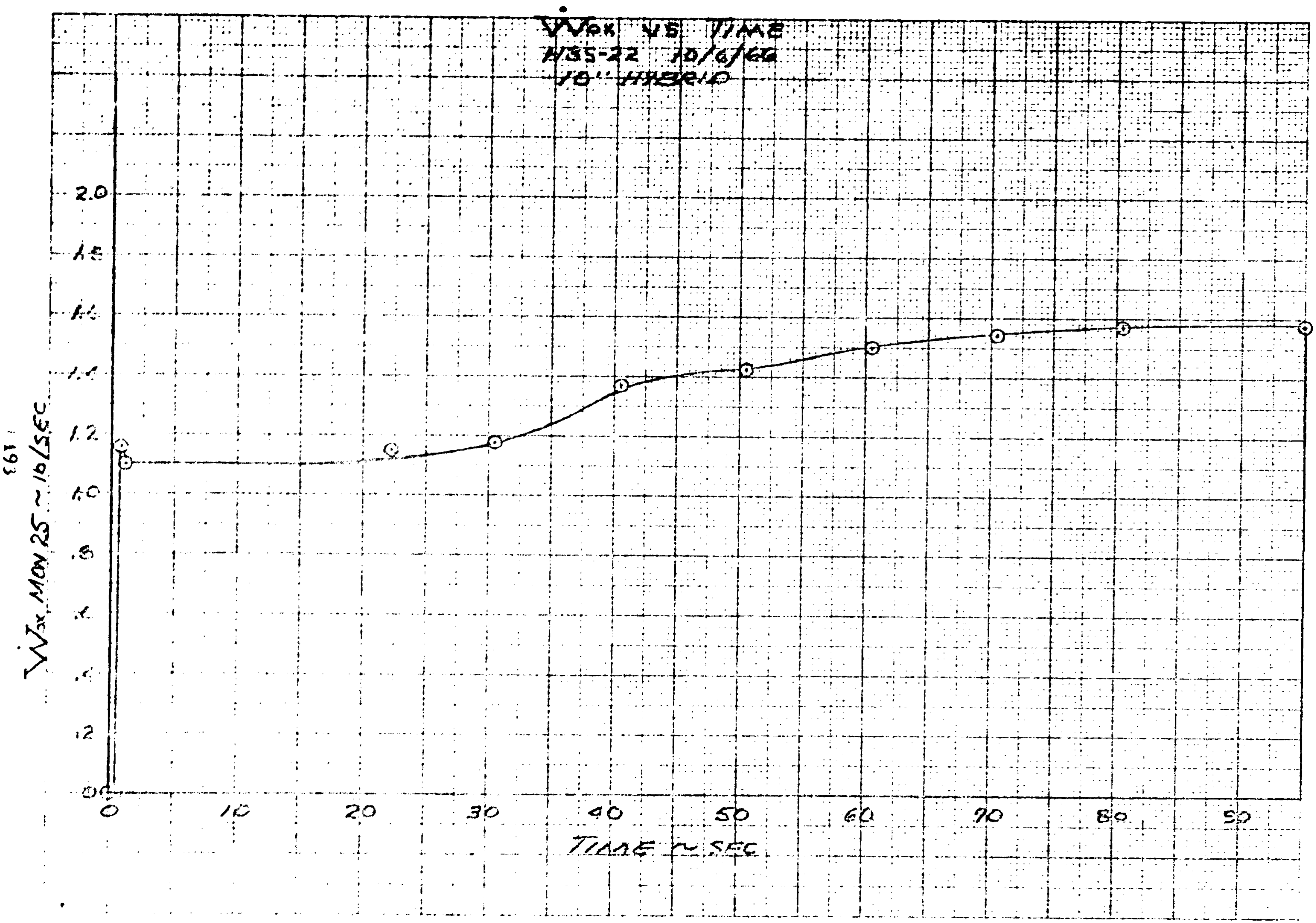
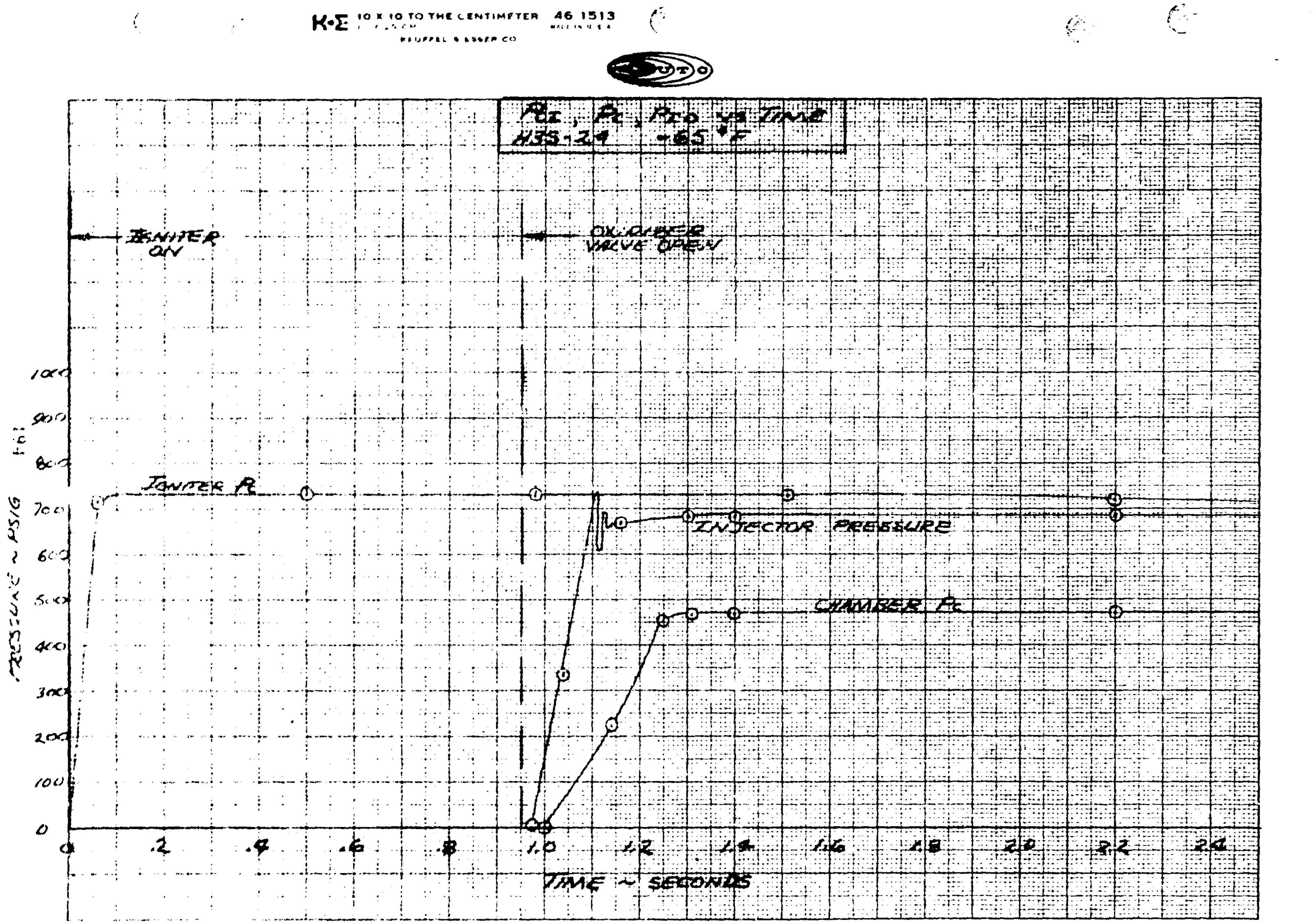
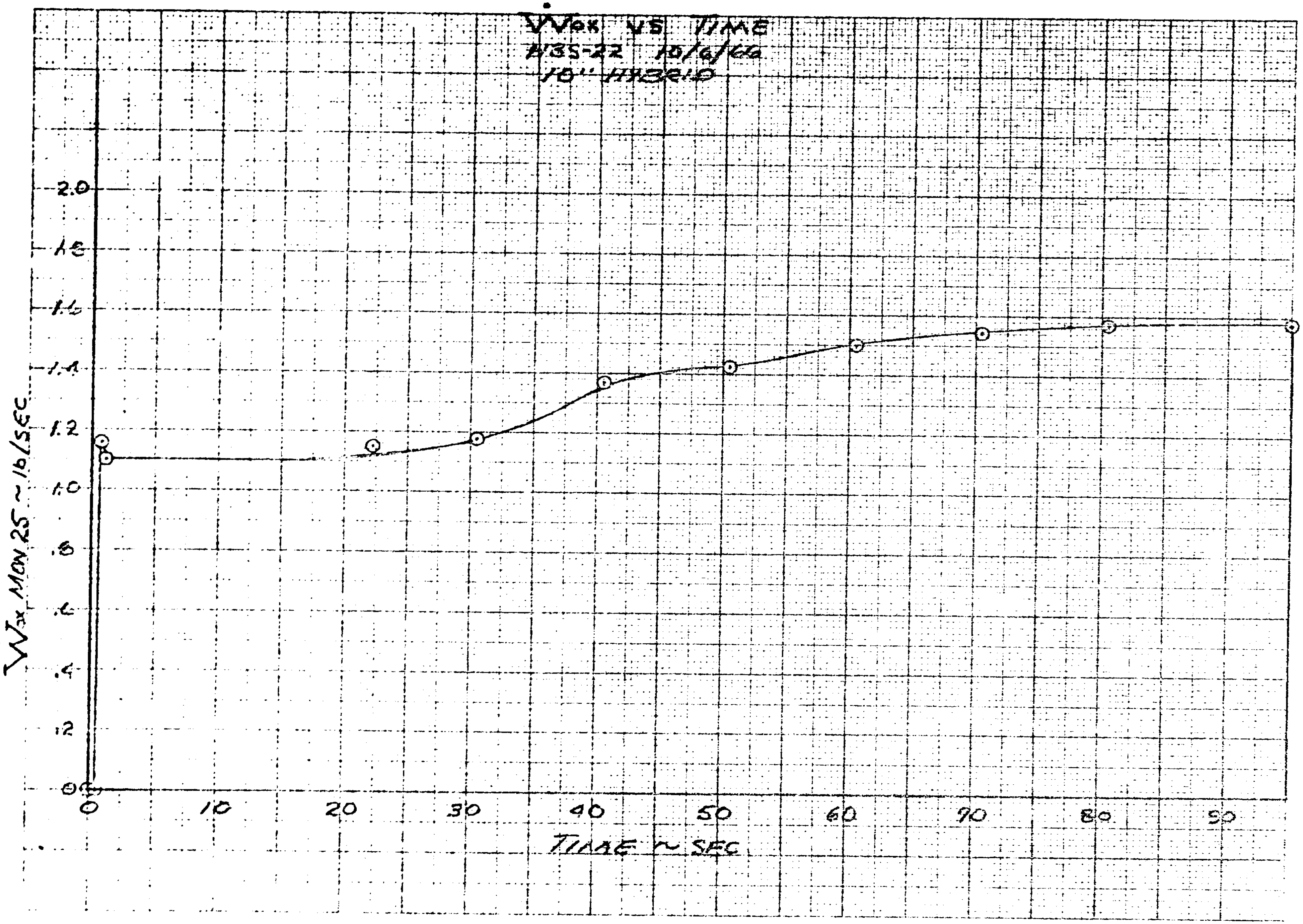

THRUST VS TIME
CONFIDENTIAL
THRUST ~ LBS


Ẇmax VS TIME
W35-22 10/6/66
18'' HYBRID
2.0
1.2
.8
.2
0
10
20
30
40
50
60
70
80
TIME ~ SEC



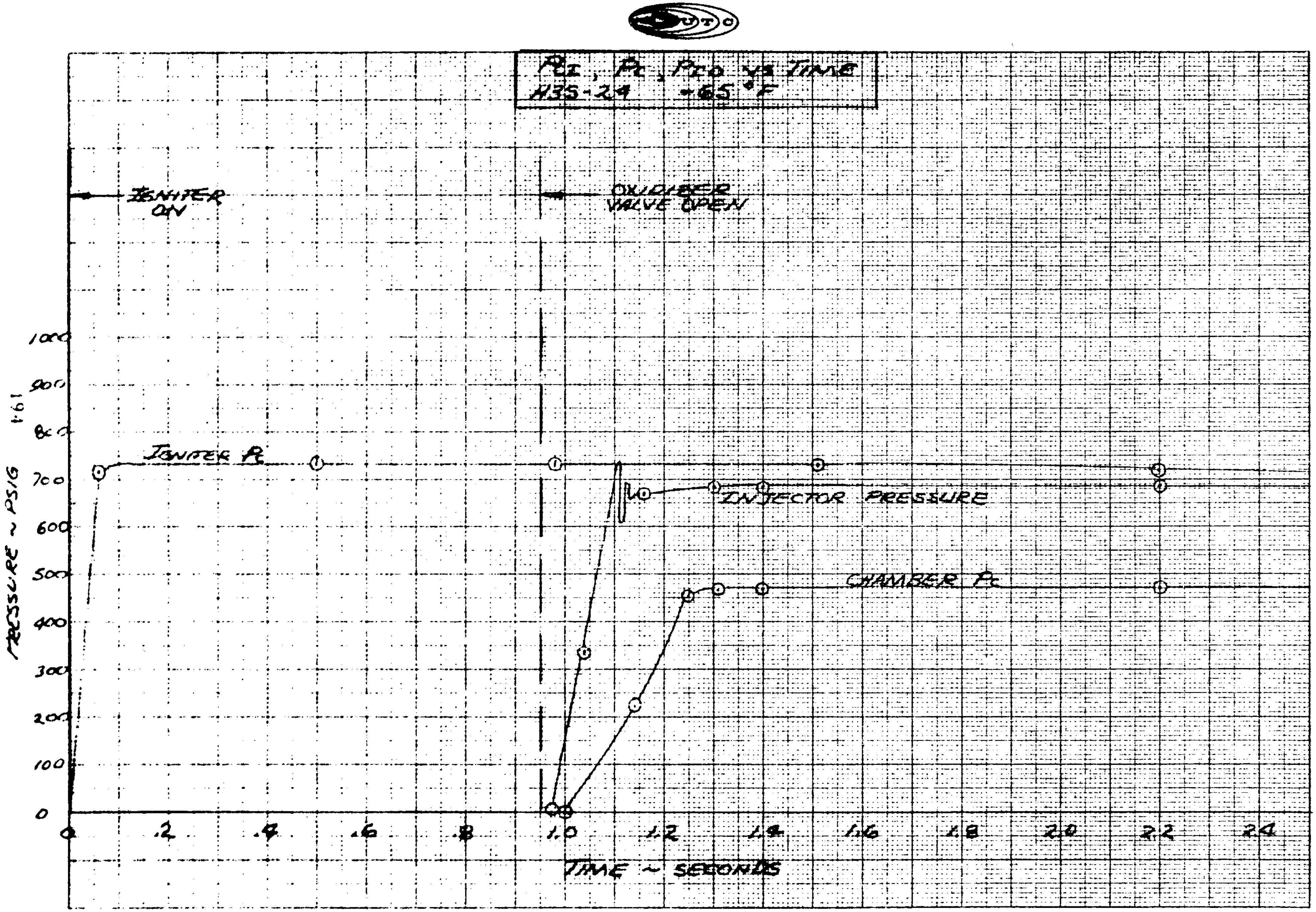
K·E 10 X 10 TO THE CENTIMETER 46 1513
KEUFFEL & ESSER CO.
P_{CI}, P_C, P_{IO} vs TIME
H35-24 +65 °F
IGNITER ON
OX. CHAMBER VALVE OPEN
IGNITER P_C
INJECTOR PRESSURE
CHAMBER P_C
PRESSURE ~ PSIG
0
100
200
300
400
500
600
700
800
900
1000
0
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
TIME ~ SECONDS

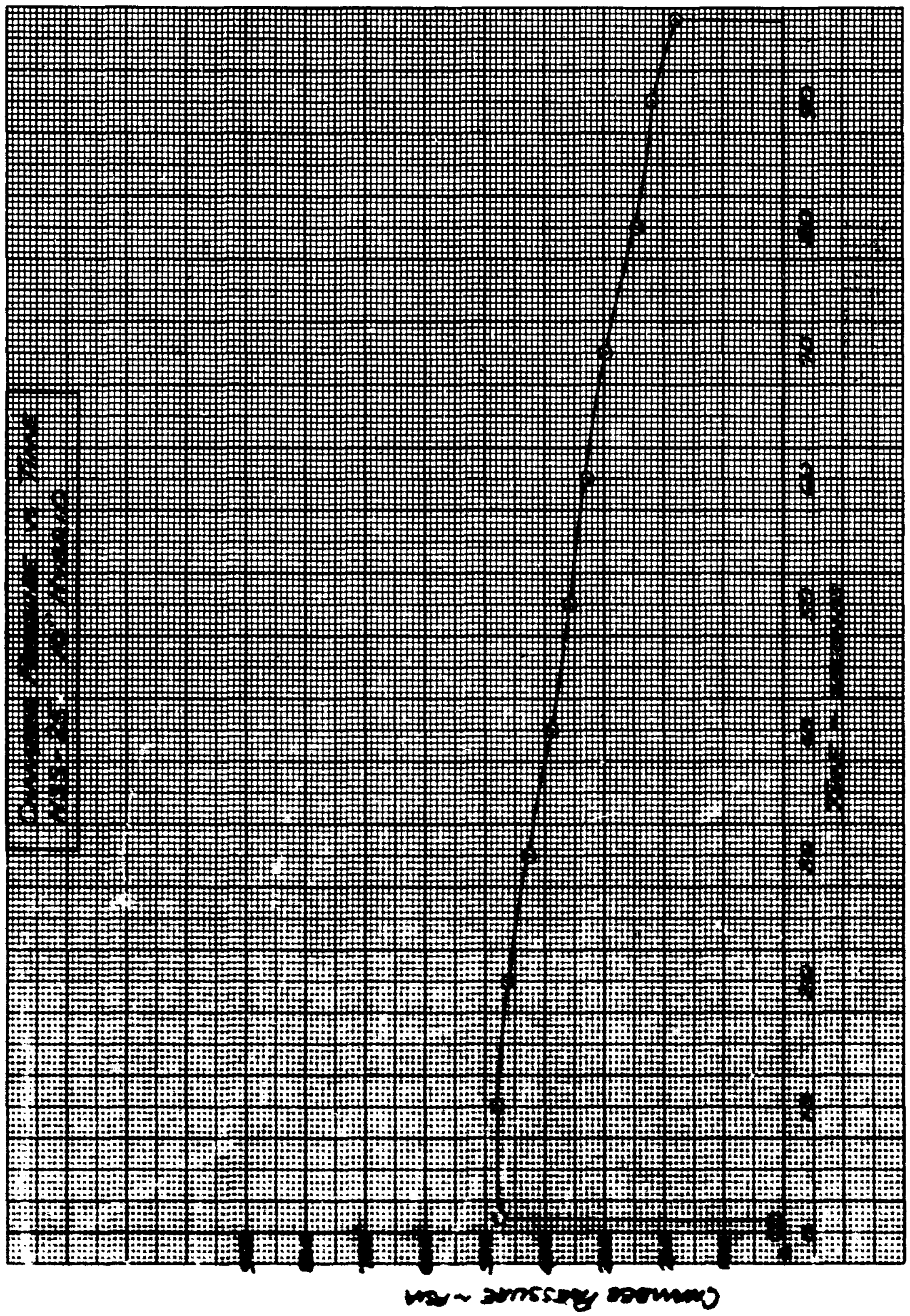
194

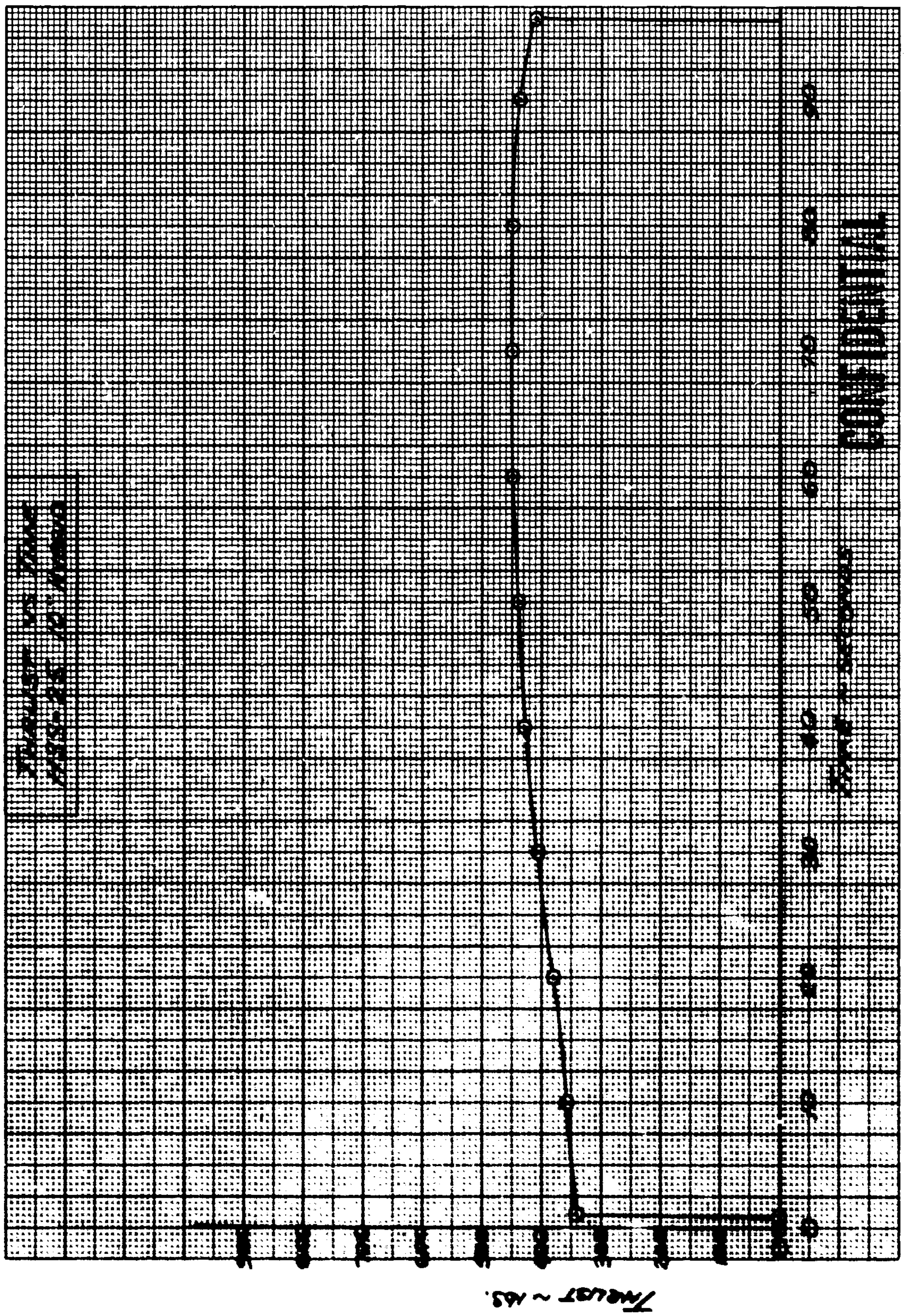


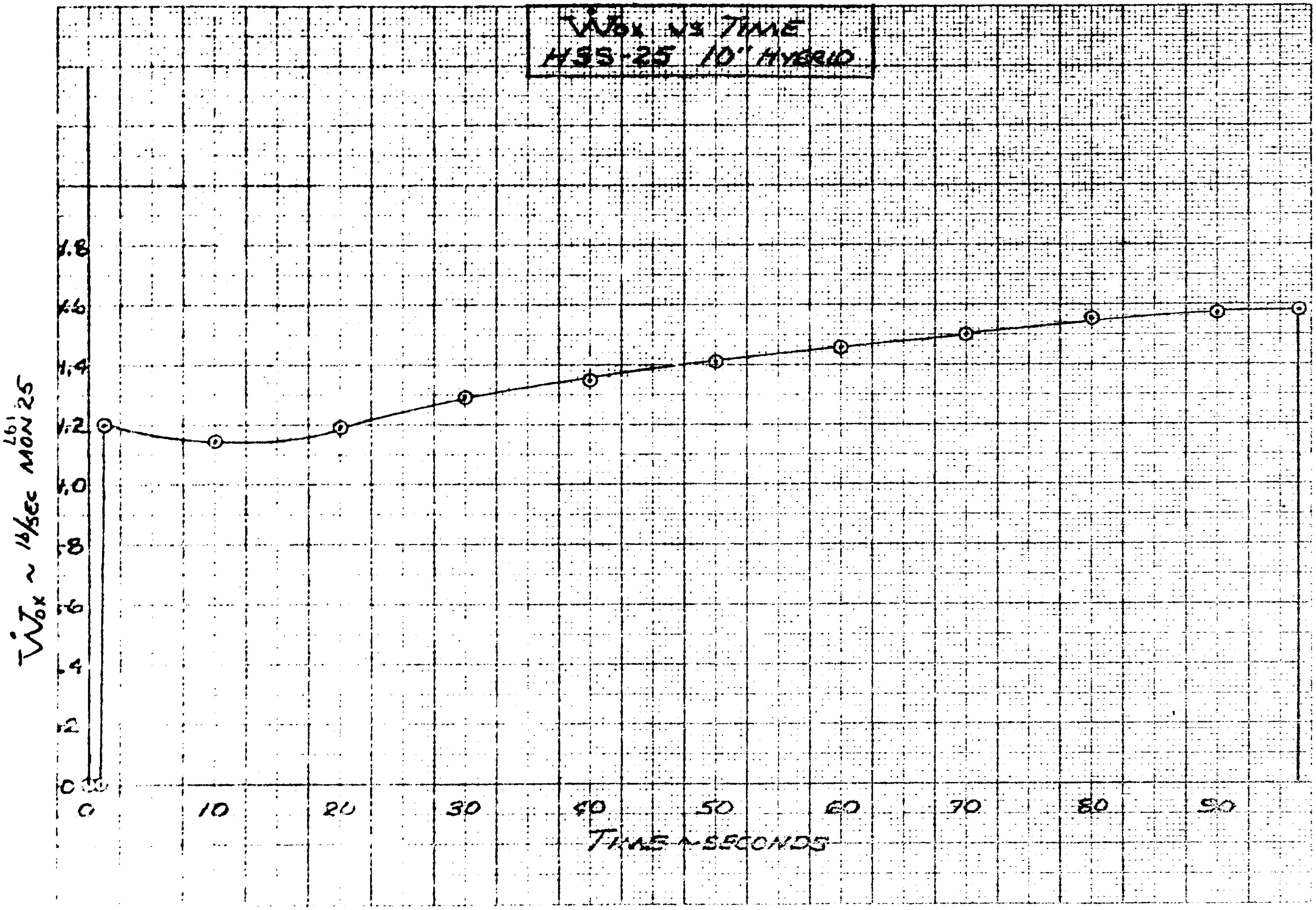
$\dot{W}_{ex}$ VS TIME
#35-22 10/6/66
10" HYBRID
2.0
1.8
1.6
1.4
1.2
1.0
.8
.6
.4
.2
0
$\dot{W}_{x}$ MON 25 ~ lb/SEC
0
10
20
30
40
50
60
70
80
90
TIME ~ SEC

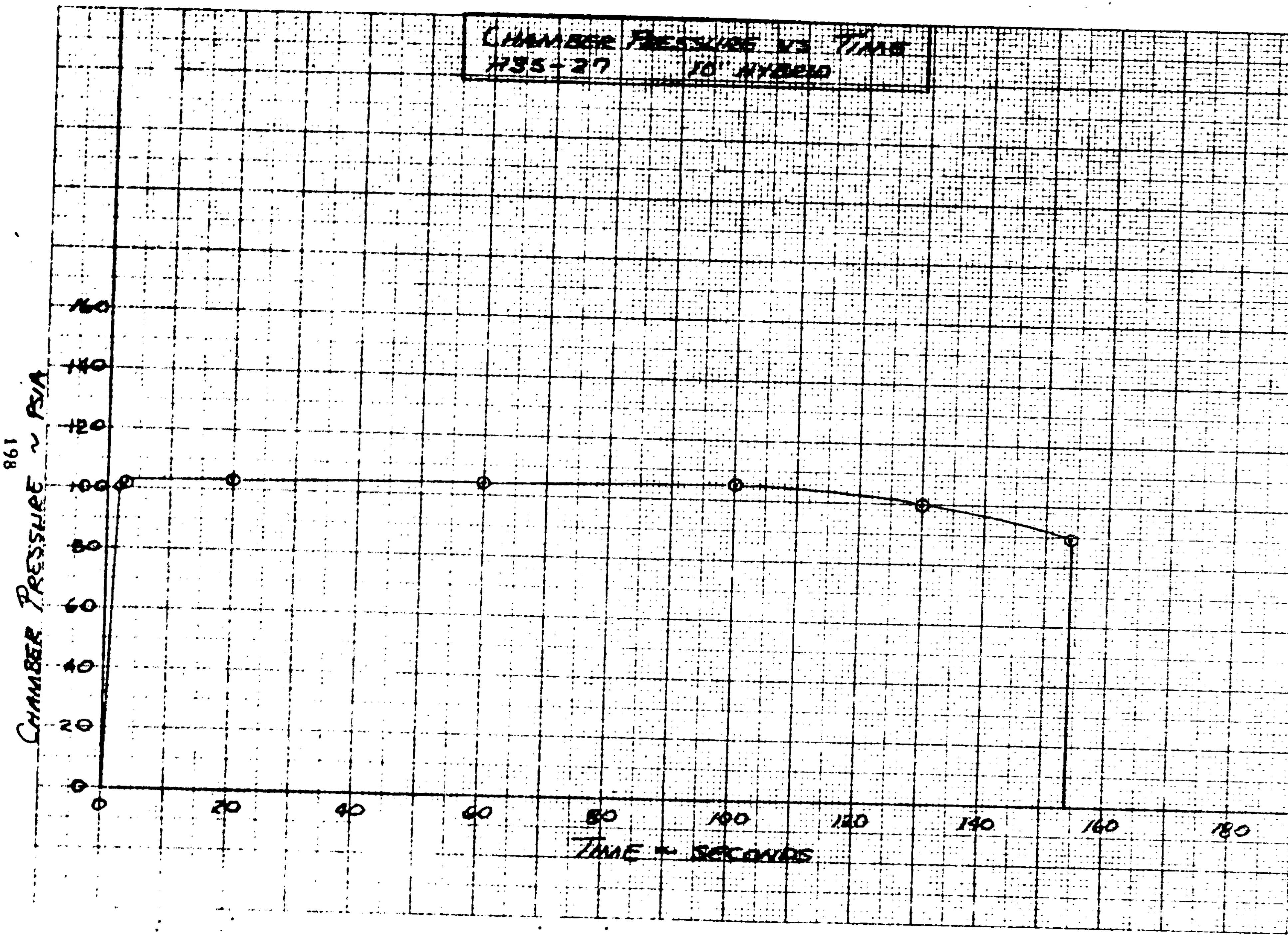
K+E 10 X 10 TO THE CENTIMETER 46 1513
KEUFFEL & ESSER CO. MADE IN U.S.A.

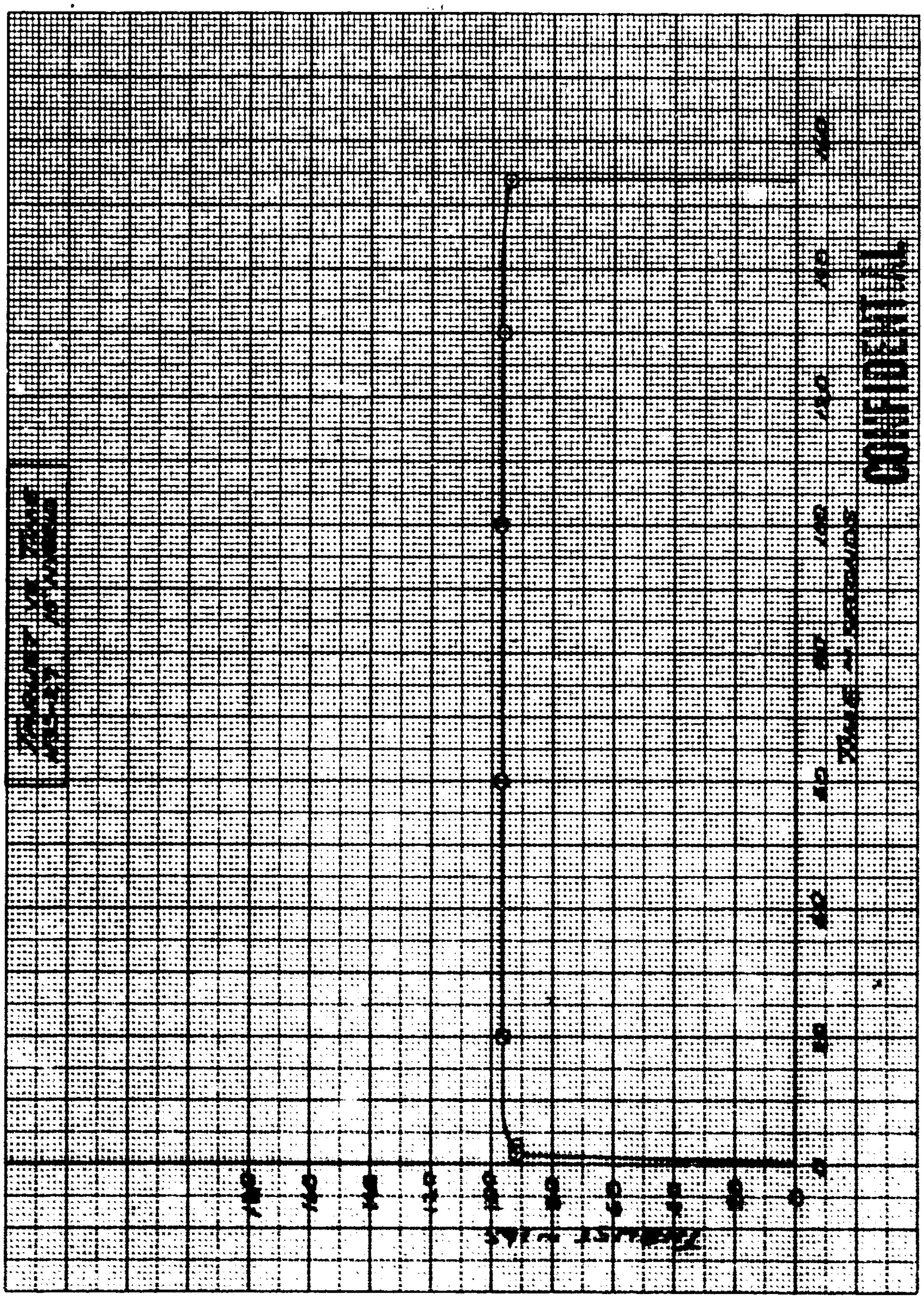


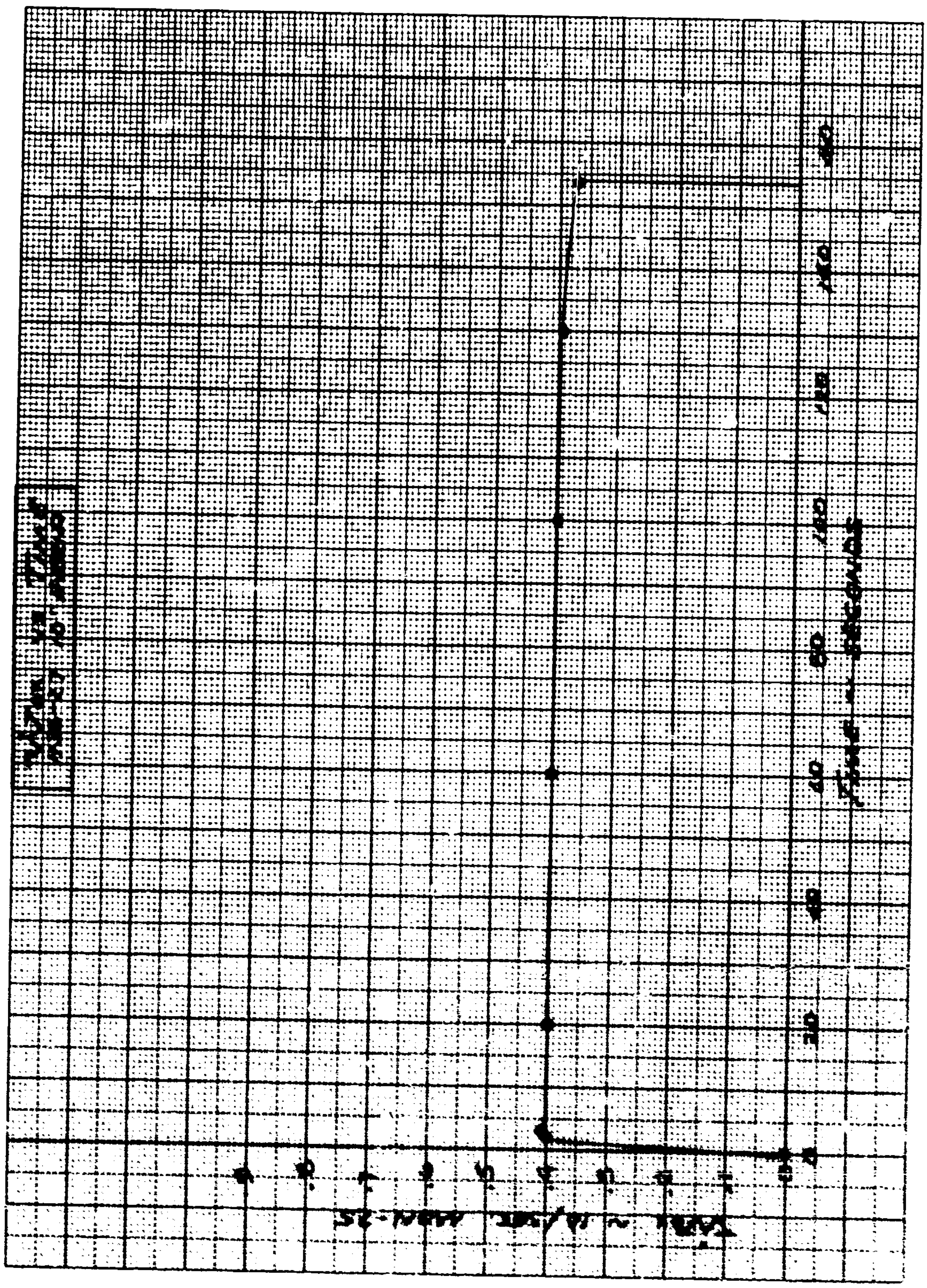


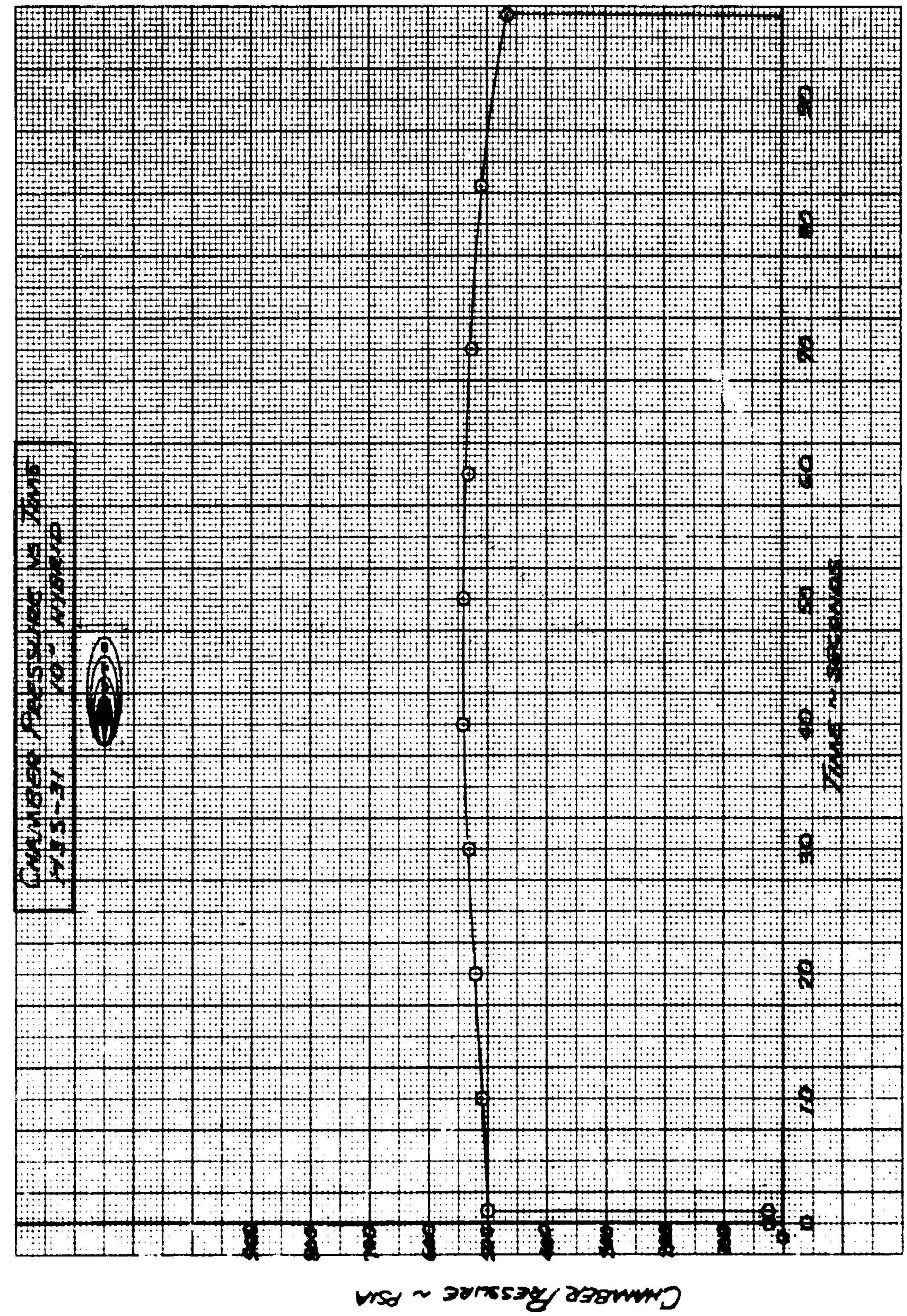

THRUST VS TIME
CONFIDENTIAL
THRUST ~ LBS.

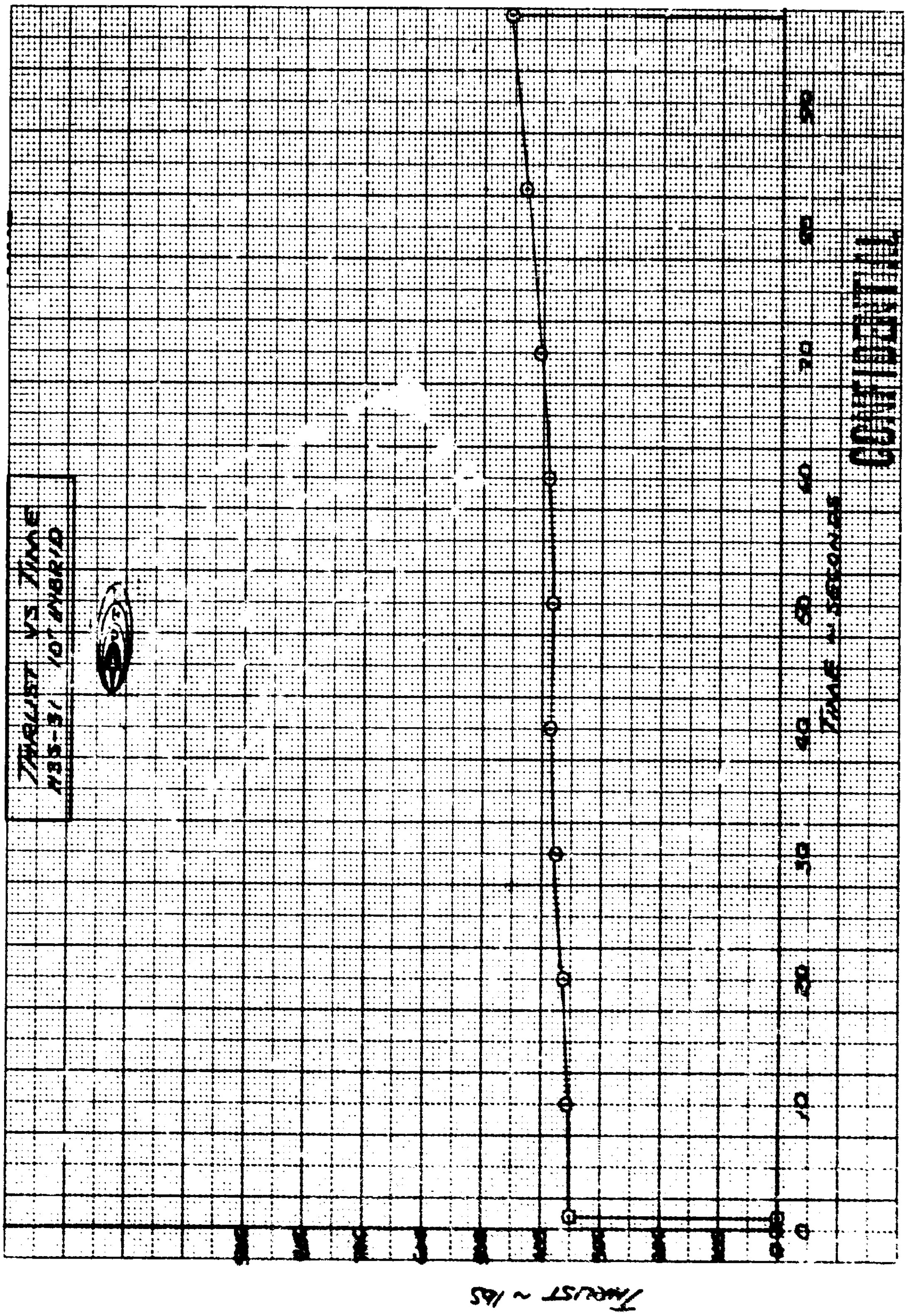

Ẇox vs TIME
HSS-25 10' HYBRID
1.8
1.6
1.4
1.2
1.0
.8
.6
.4
.2
0
0
10
20
30
40
50
60
70
80
90
TIME ~ SECONDS
Ẇox ~ lb/sec MON 25

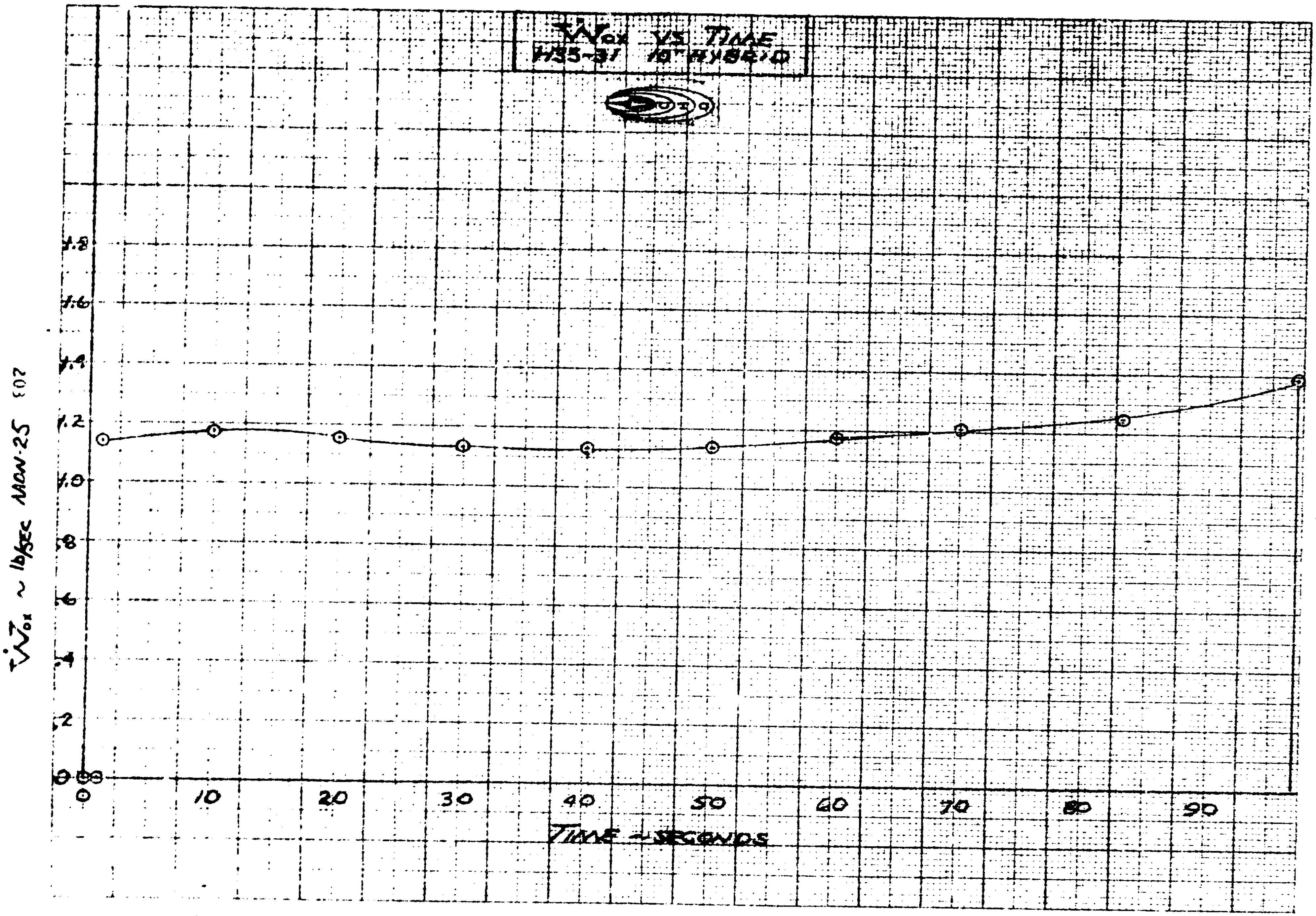

CHAMBER PRESSURE VS TIME
#35-27 10" HYBRID
CHAMBER PRESSURE ~ PSIA
0
20
40
60
80
100
120
140
160
0
20
40
60
80
100
120
140
160
180
TIME ~ SECONDS

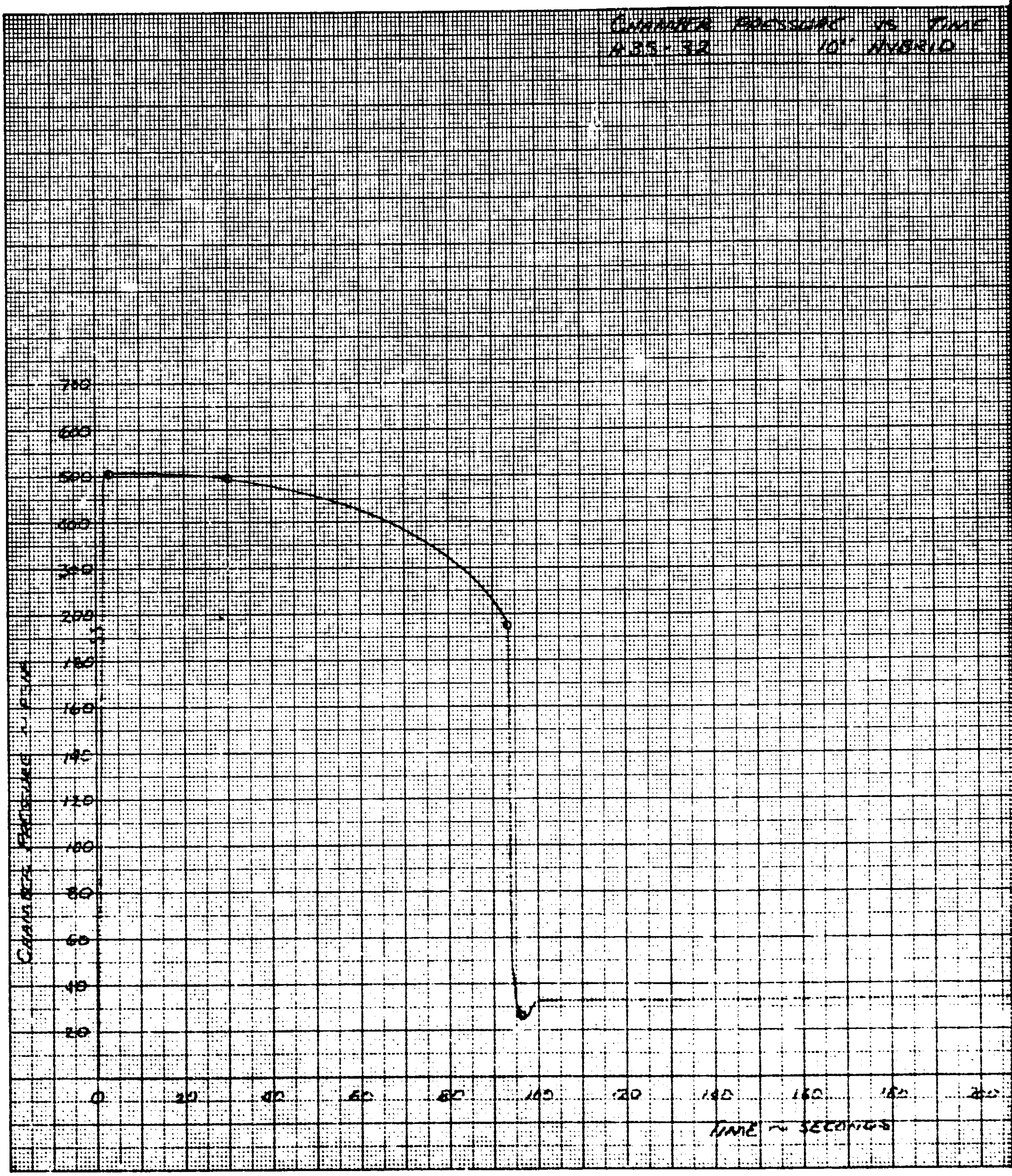




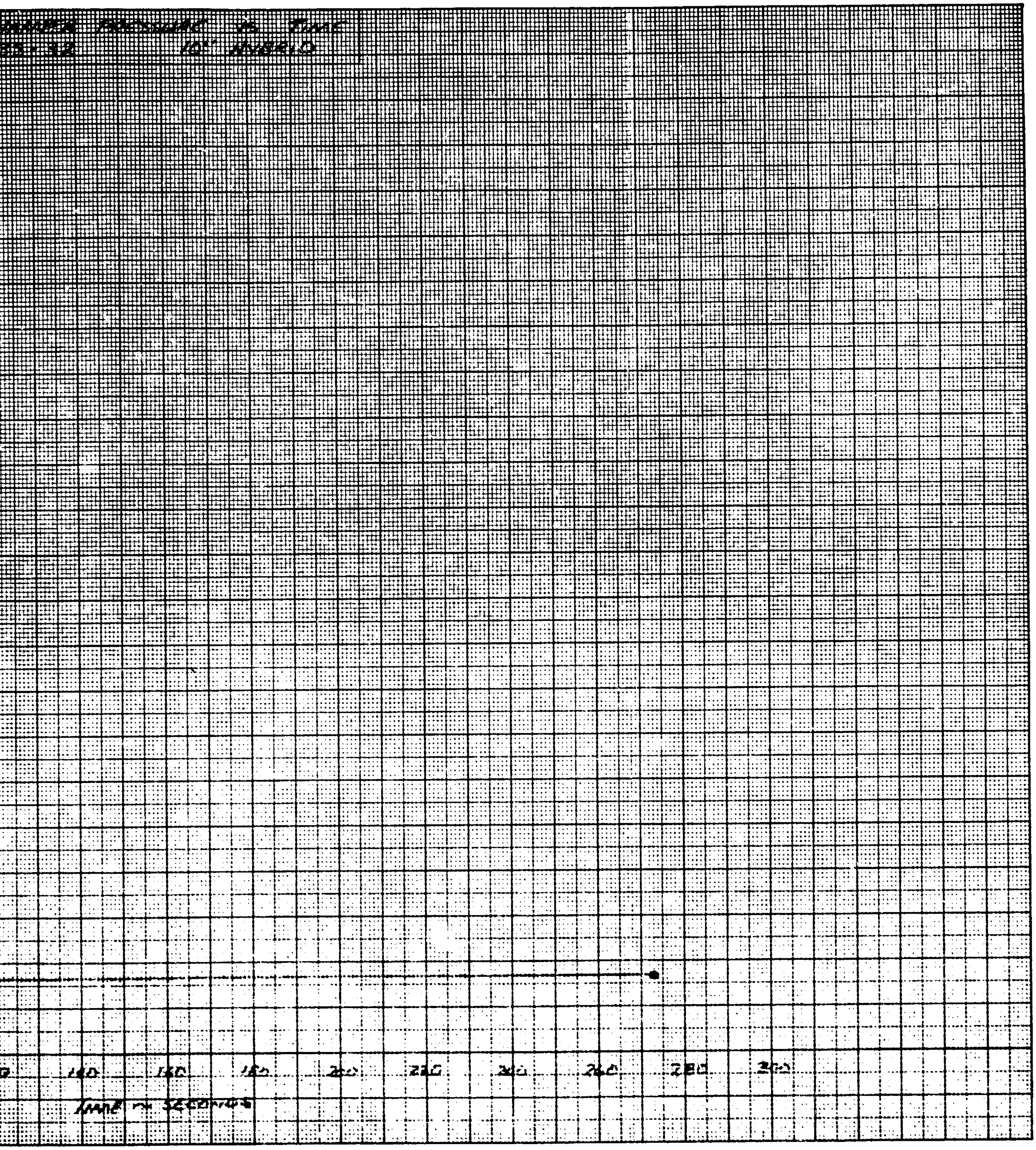

Chamber Pressure vs Time
Time ~ Seconds
Chamber Pressure ~ PSIA


THRUST VS TIME
M55-31 10" HYBRID
TIME ~ SECONDS
0
10
20
30
40
50
60
70
80
90
THRUST ~ LBS
CONFIDENTIAL

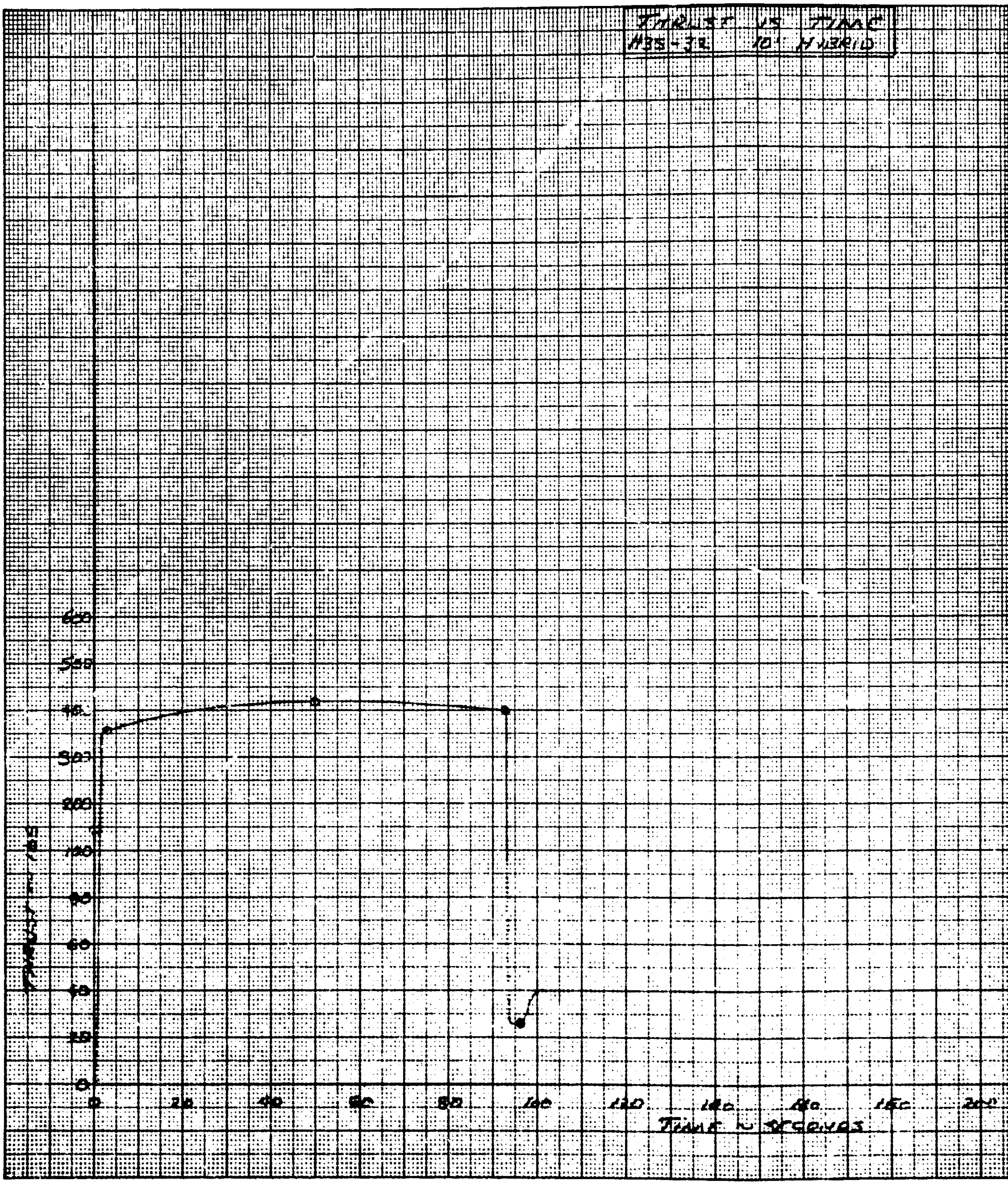

$\dot{W}_{ox}$ VS TIME
H35-31 10" HYBRID
1.8
1.6
1.4
1.2
1.0
.8
.6
.4
.2
0
0
10
20
30
40
50
60
70
80
90
TIME ~ SECONDS
$\dot{W}_{ox}$ ~ lb/sec MON-25

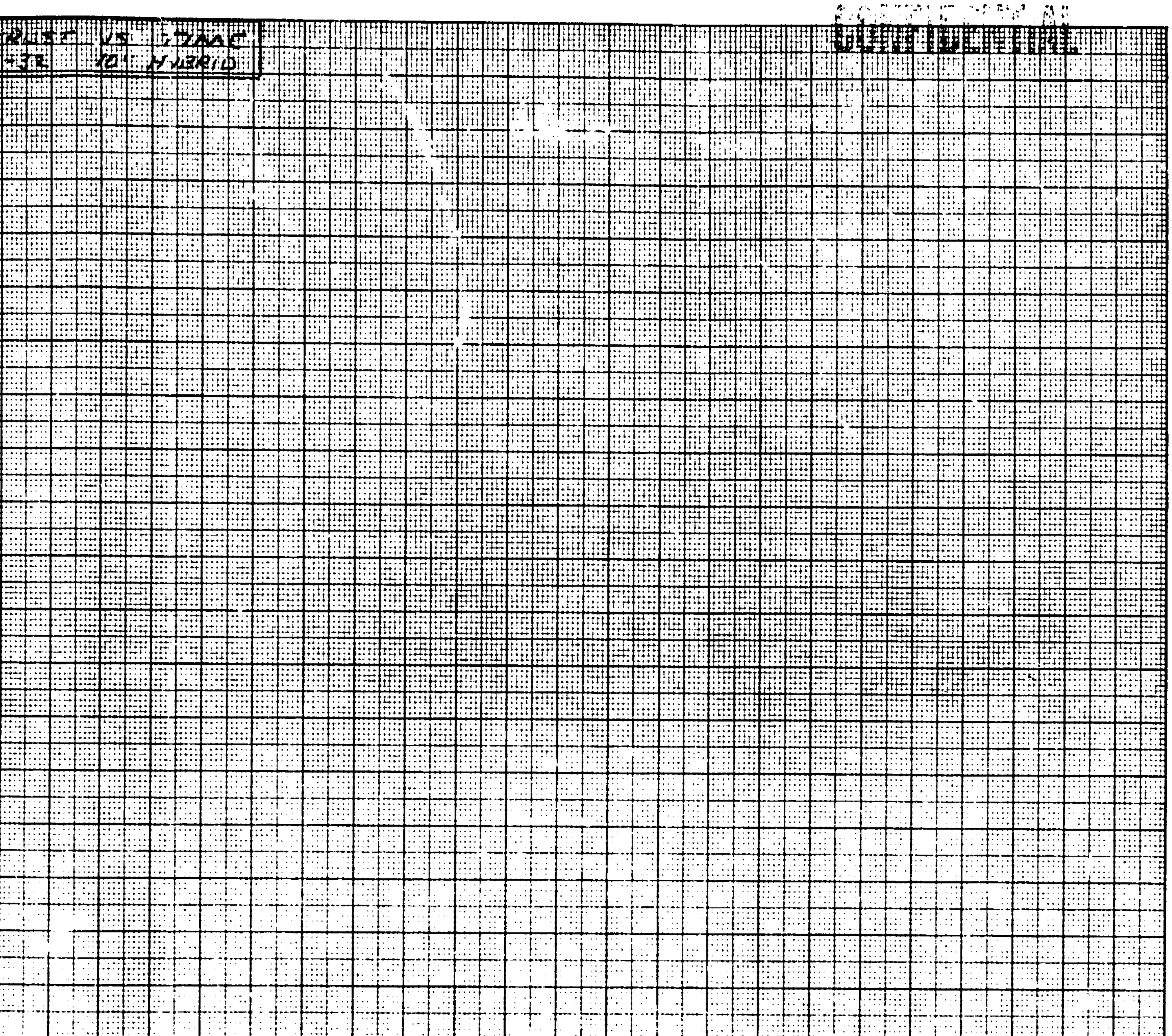


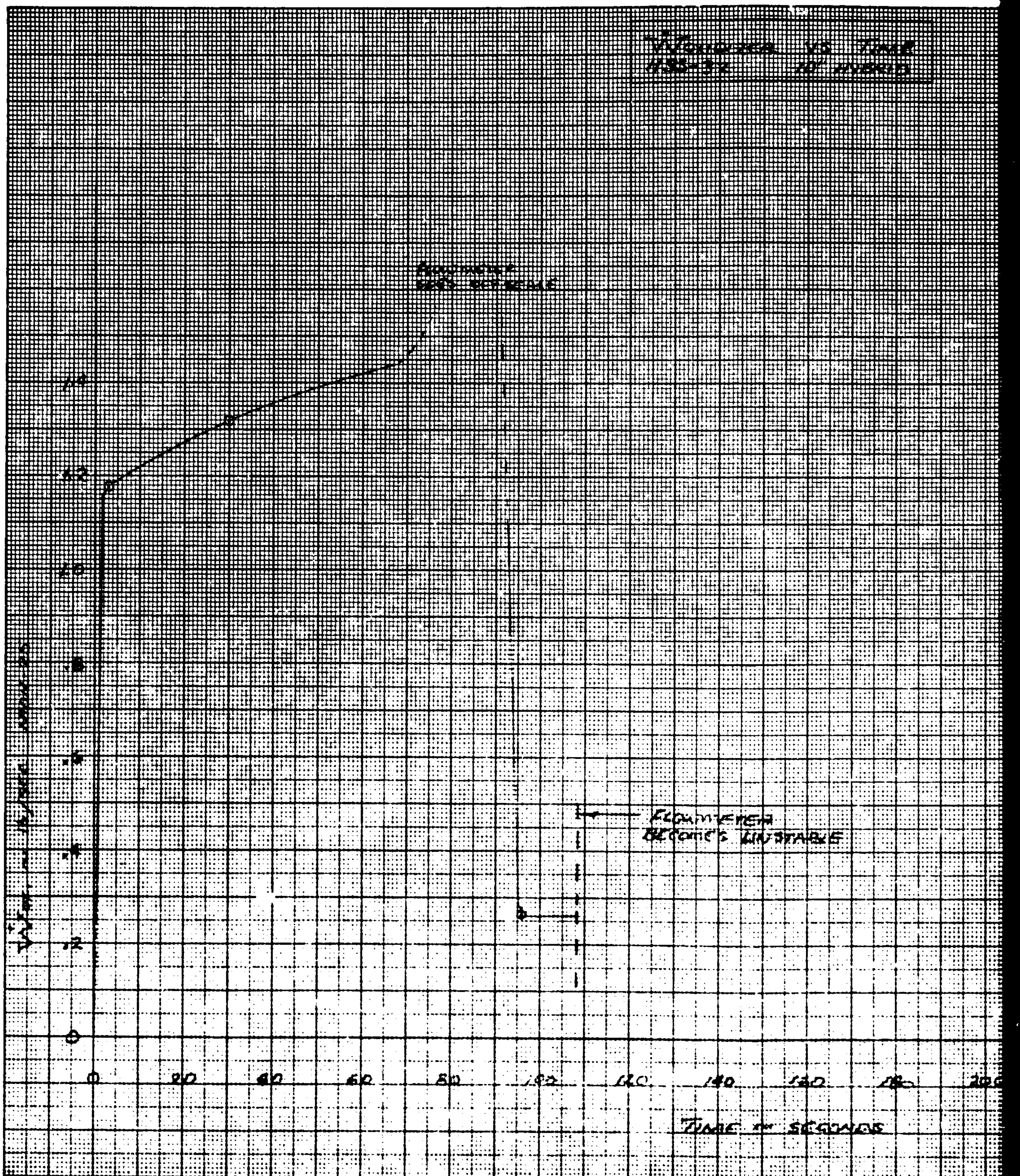
CHAMBER PRESSURE VS TIME
A35-32 10" HYBRID
CHAMBER PRESSURE ~ PSIA
TIME ~ SECONDS



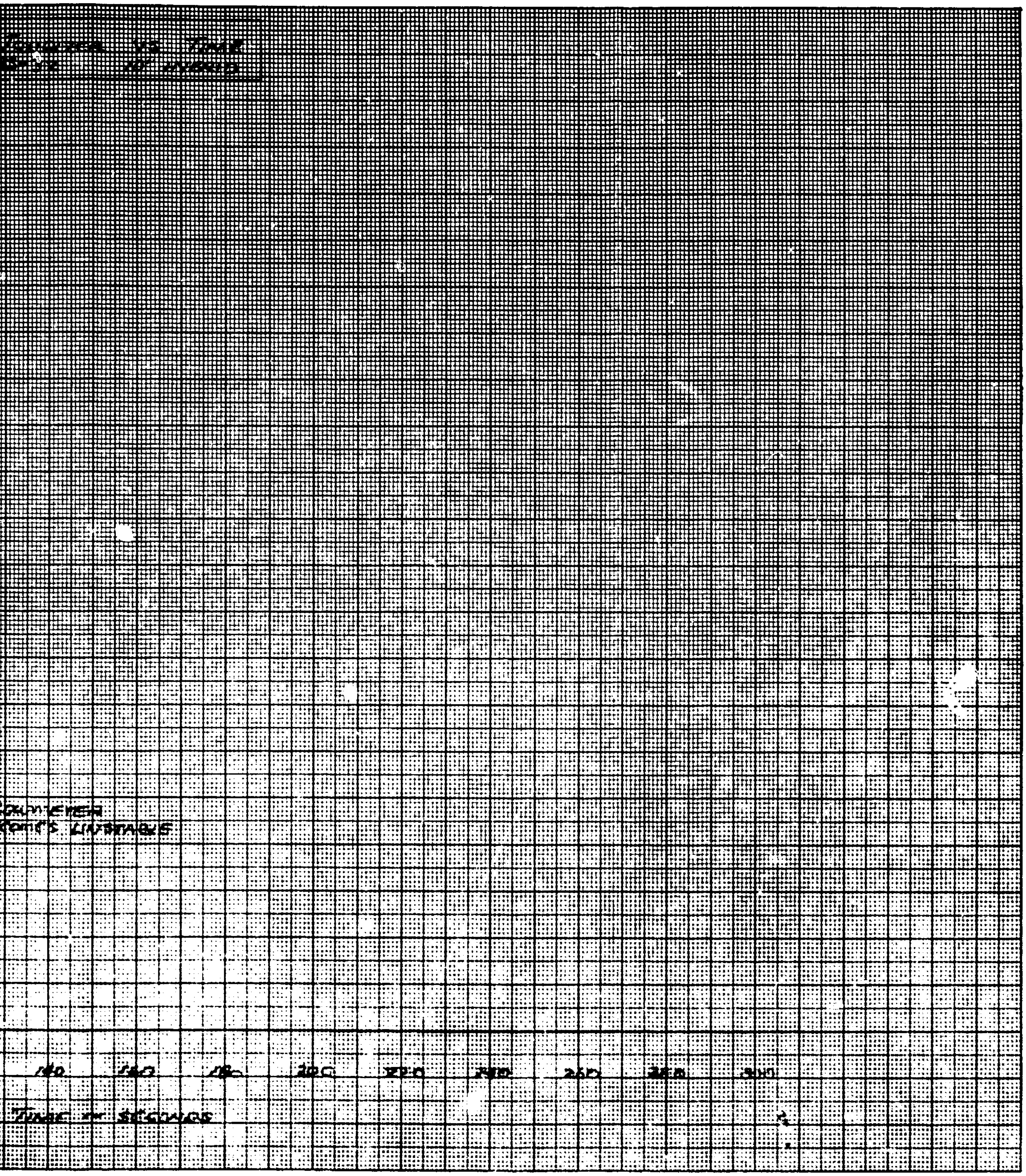
...AMBER PRESSURE VS TIME
...5-12 10" HYBRID
140 160 180 200 220 240 260 280 300
TIME ~ SECONDS


THRUST VS TIME
#35-32 10' HYBRID
TIME ~ SECONDS
0
20
40
60
80
100
120
140
160
180
200
300
400
500
600

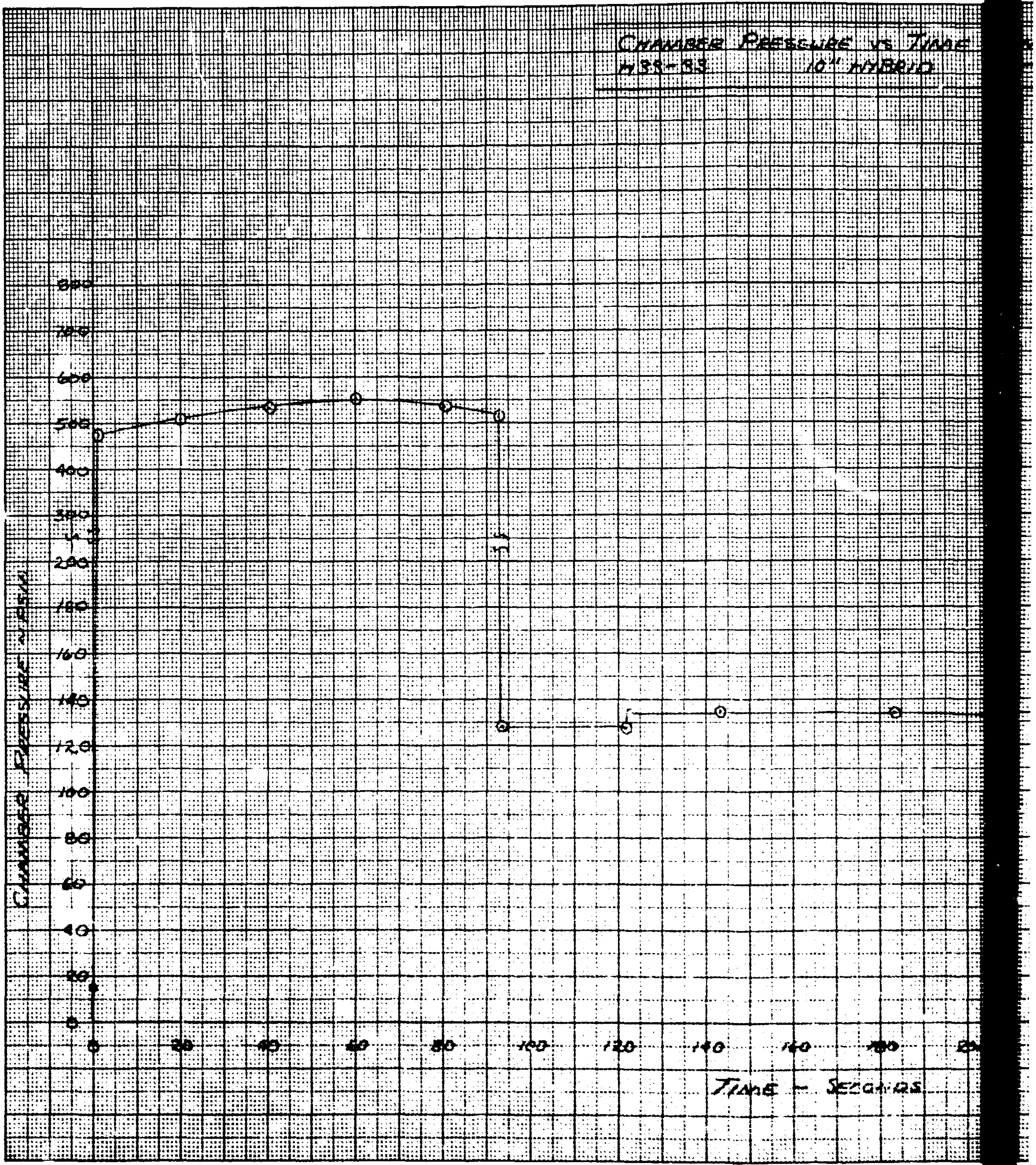


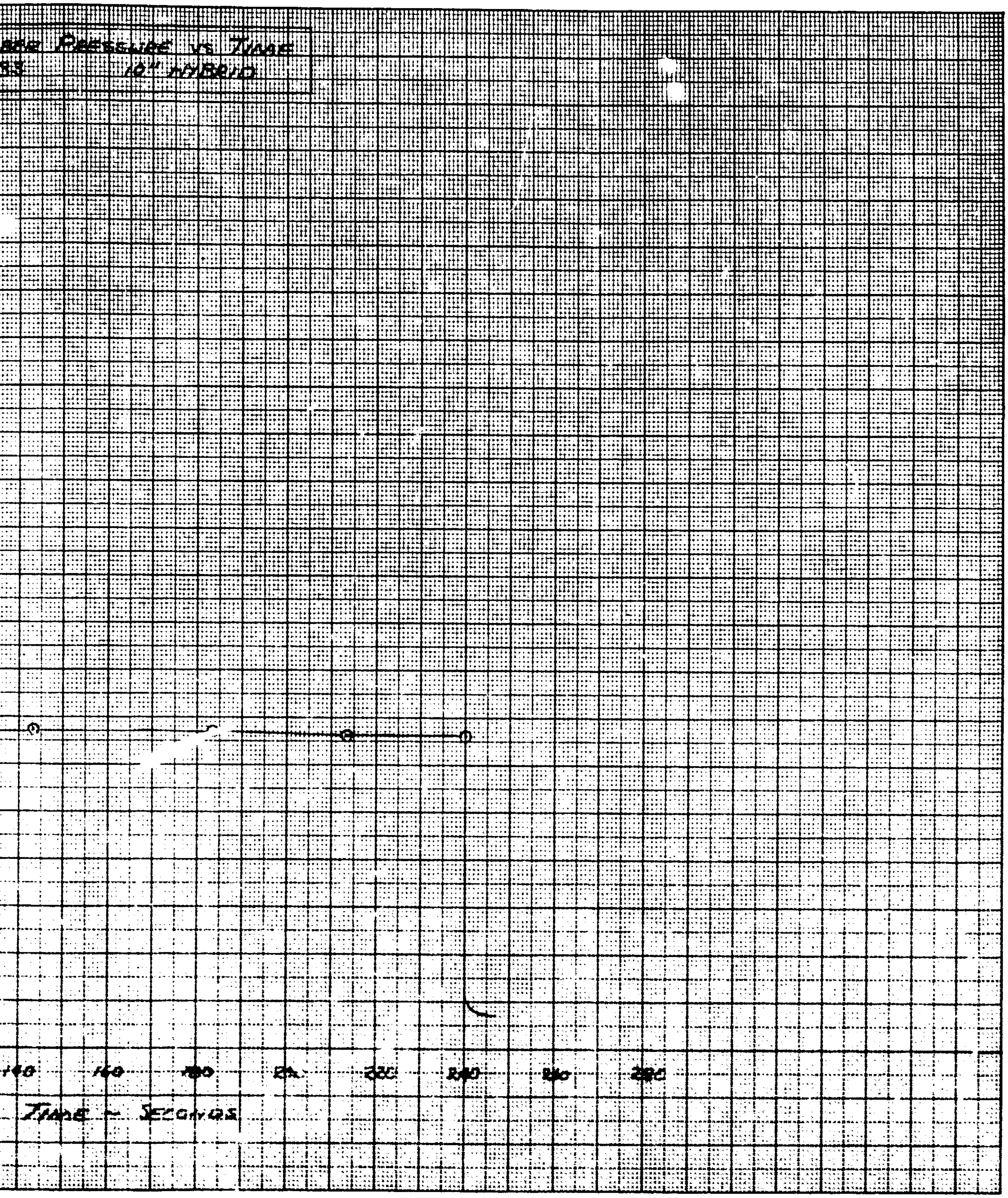


$\dot{W}$OXIDIZER VS TIME
1135-3X 10" HYBRID
FLOWMETER BECOMES UNSTABLE
TIME ~ SECONDS



140
160
200
260
TIME — SECONDS


CHAMBER PRESSURE VS TIME
H33-33 10" HYBRID
CHAMBER PRESSURE ~ PSIA
800
700
600
500
400
300
200
180
160
140
120
100
80
60
40
20
0
20
40
60
80
100
120
140
160
180
TIME ~ SECONDS



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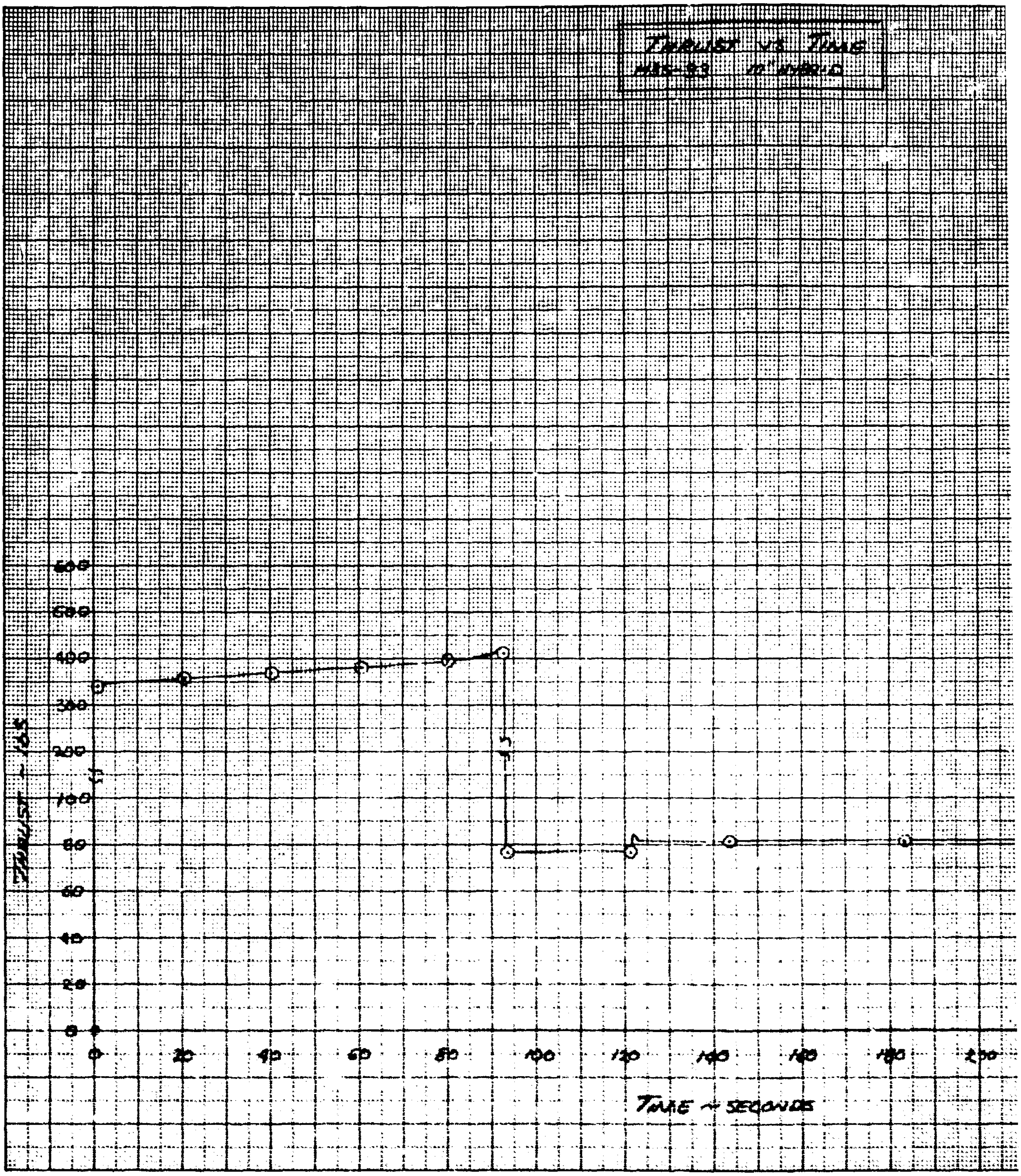
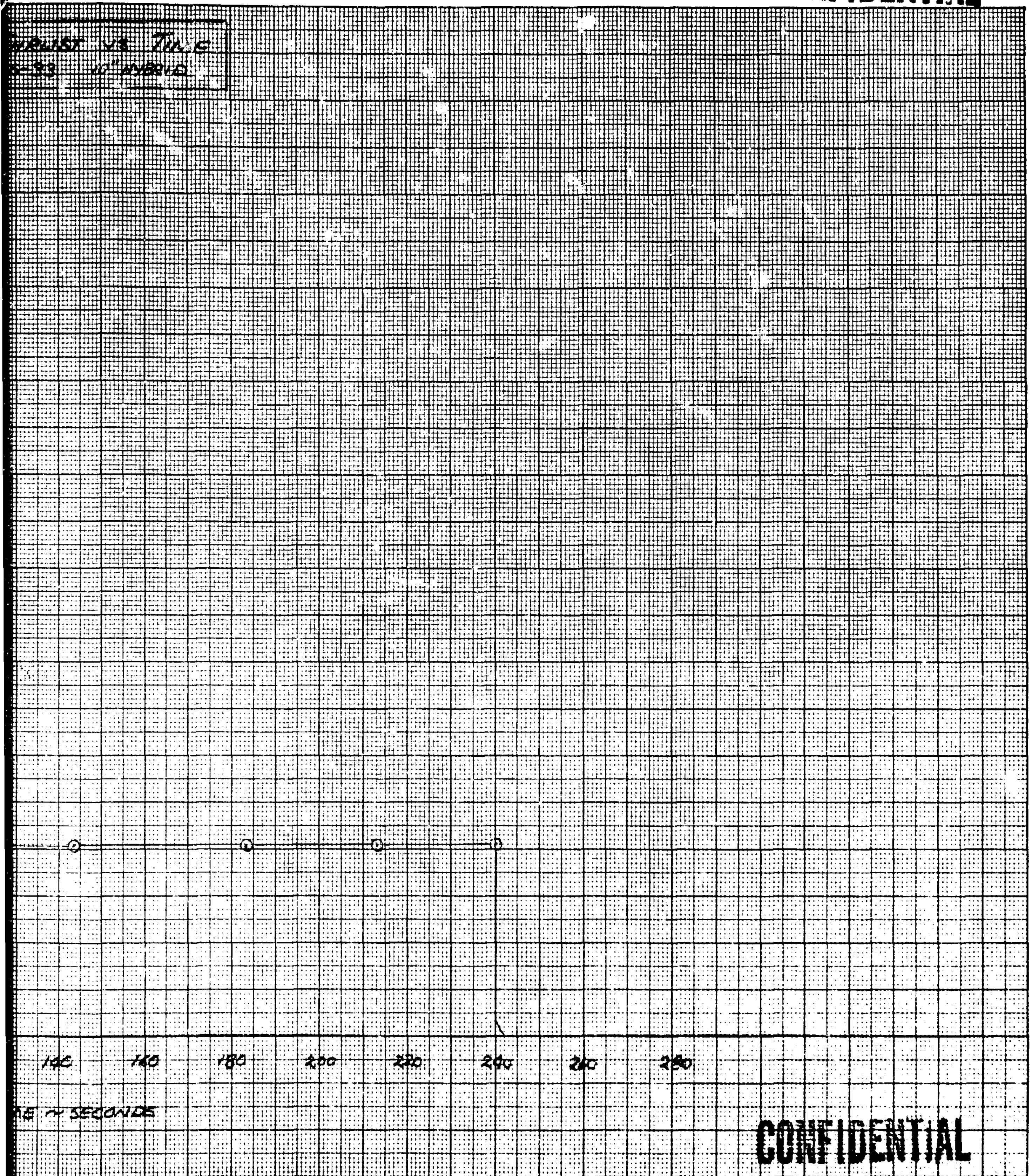
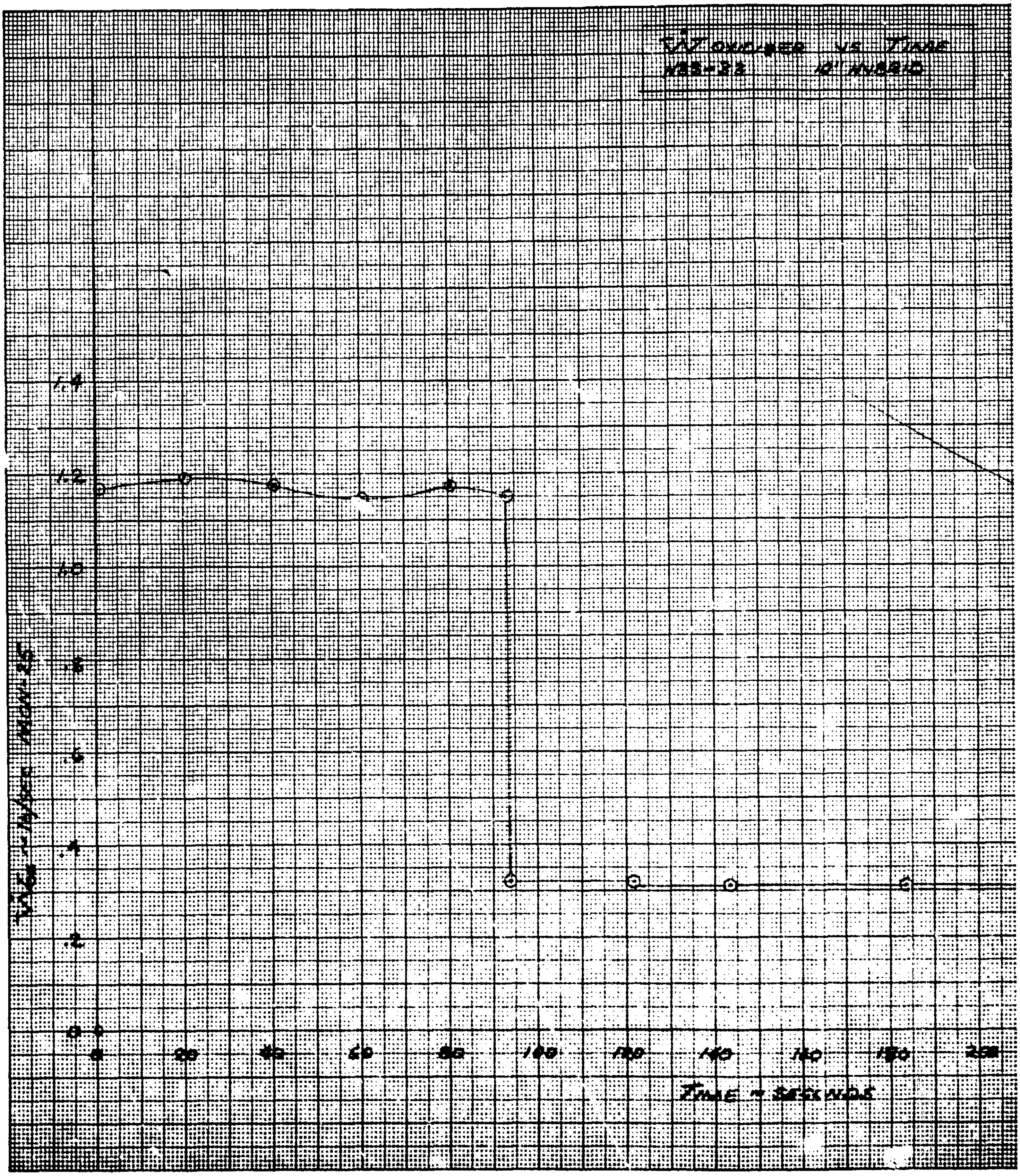

THRUST VS TIME
THRUST ~ LBS
TIME ~ SECONDS
0
20
40
60
80
100
120
140
160
180
200
300
400

CONFIDENTIAL

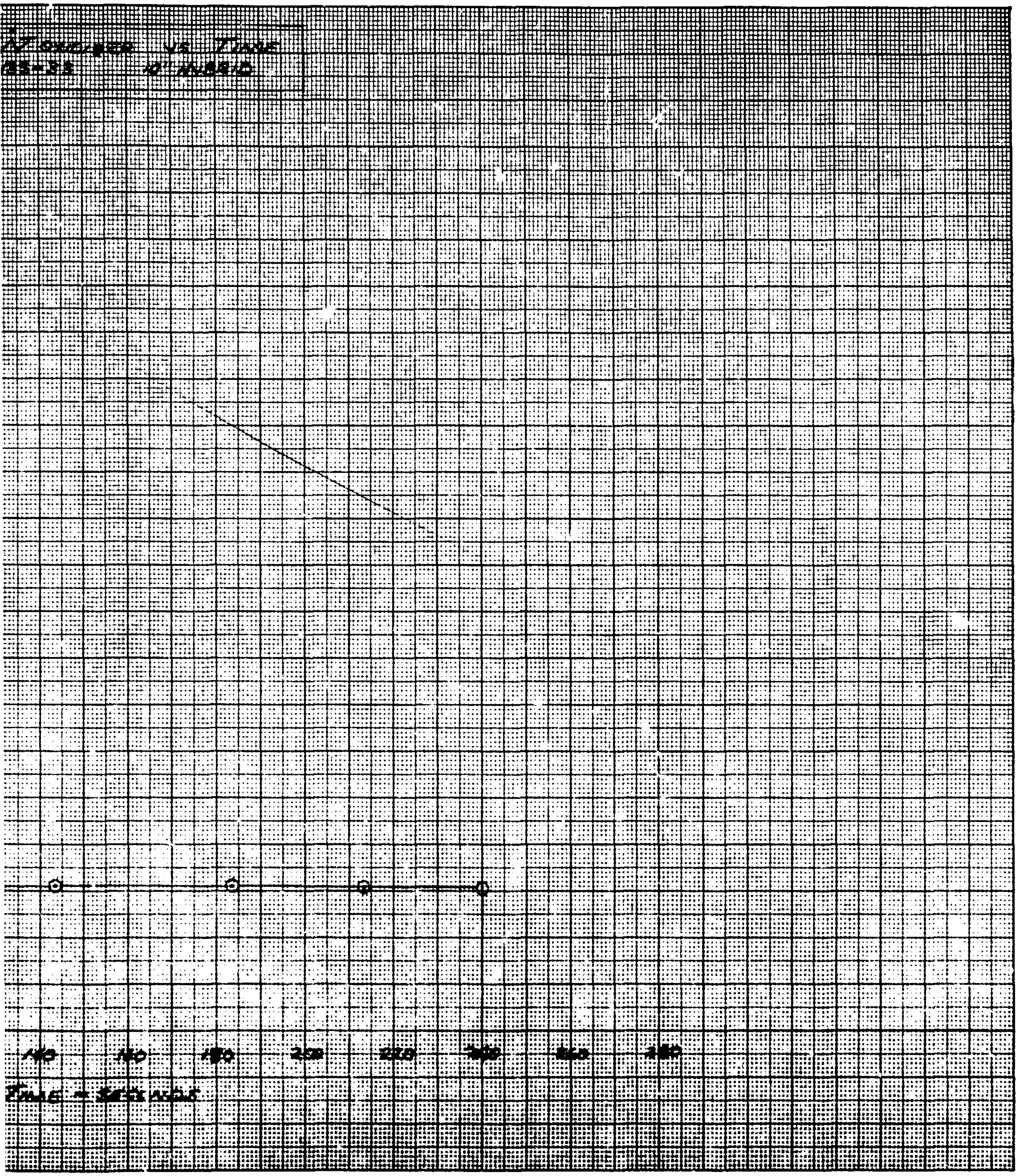


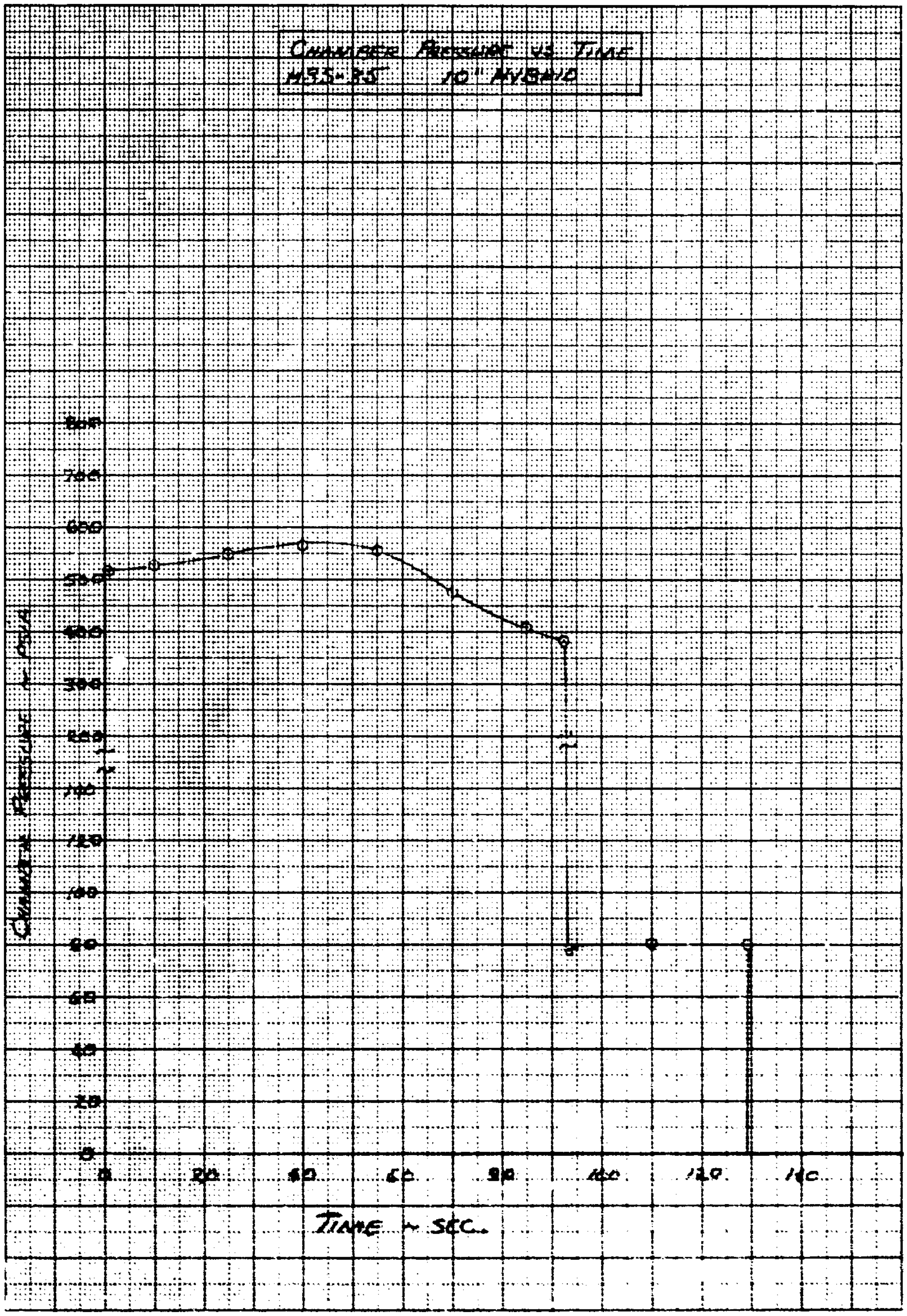
CONFIDENTIAL

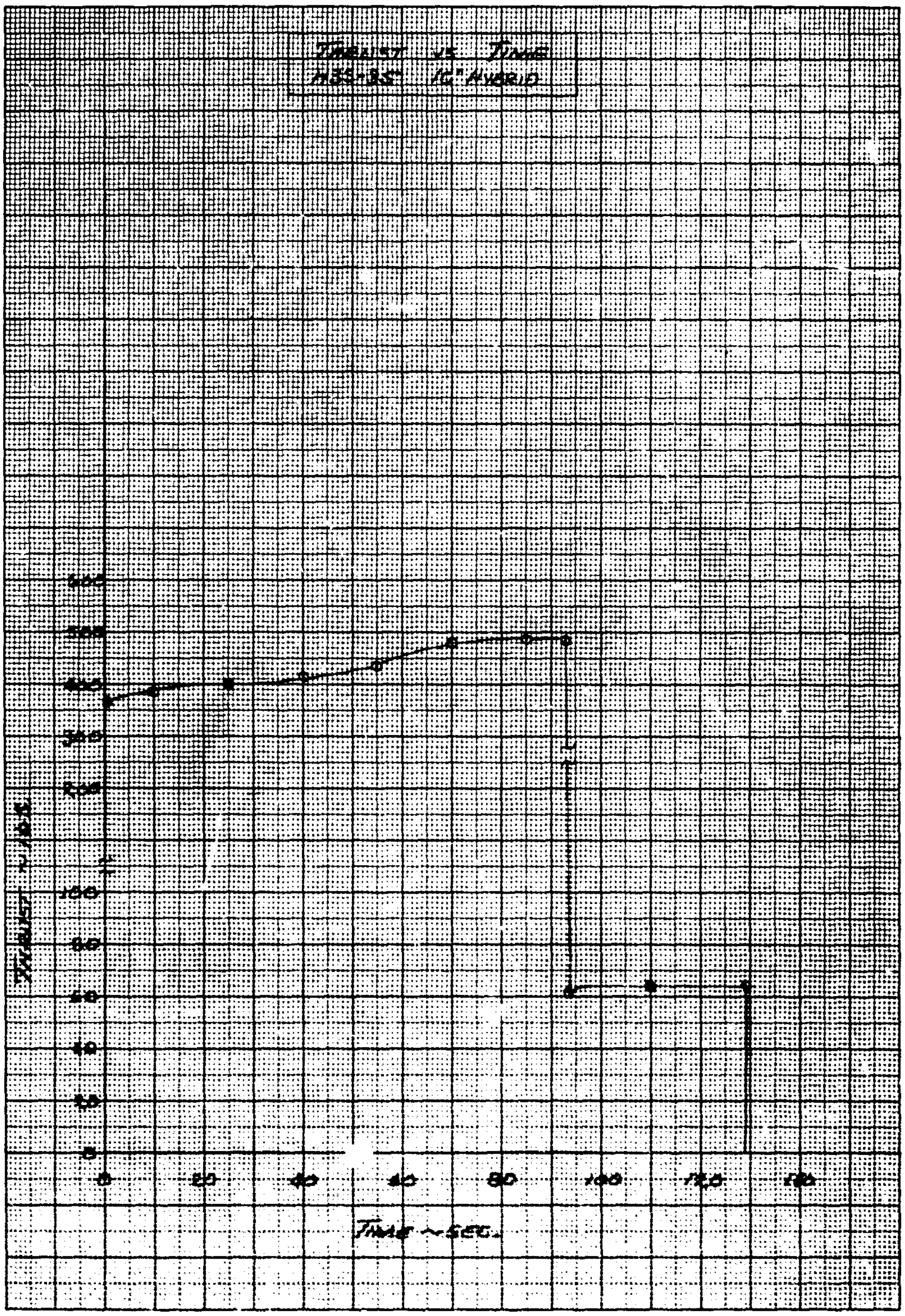
γ

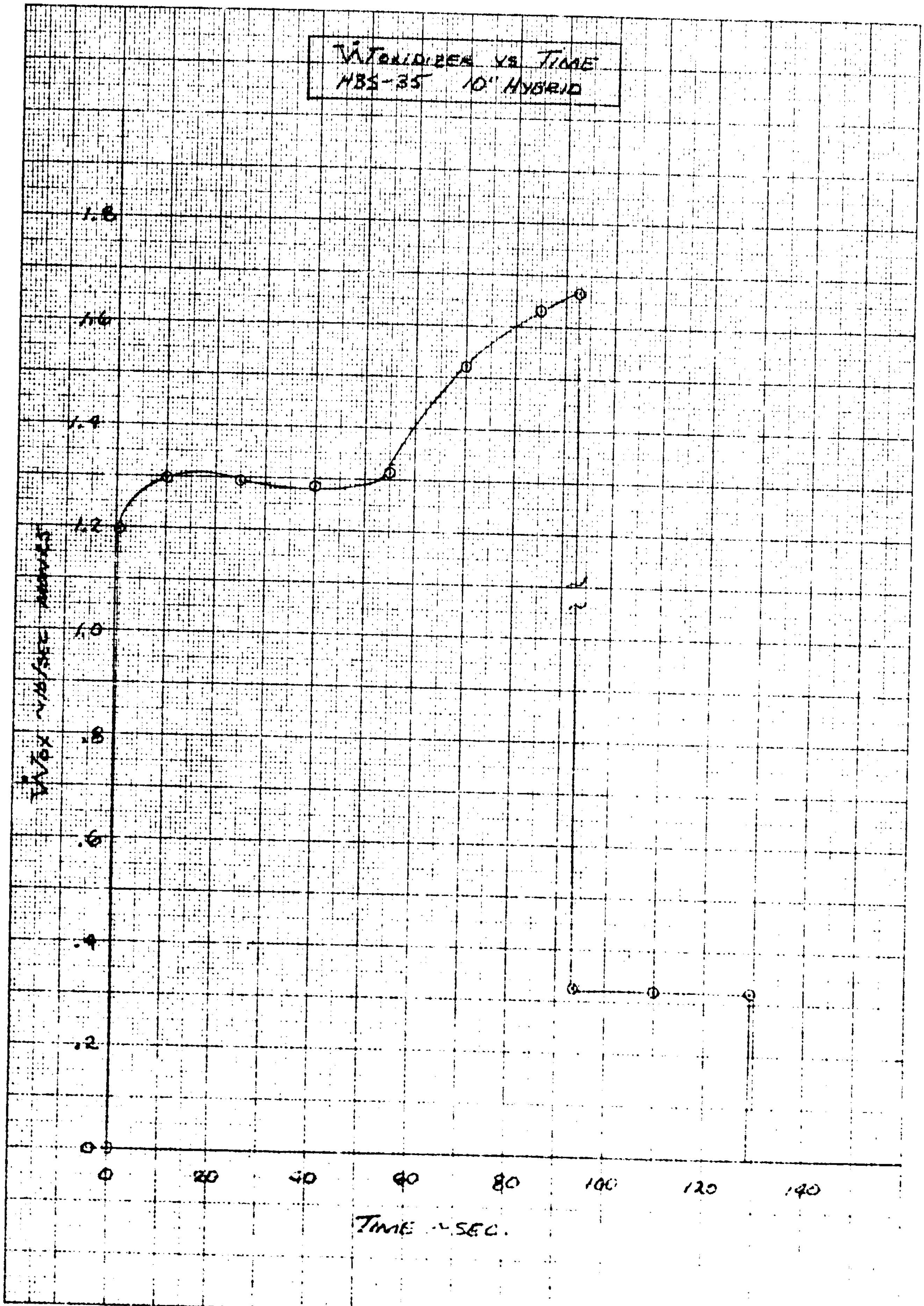


ẆOXIDIZER VS TIME
1.4
1.2
1.0
.8
.6
.4
.2
0
0
20
40
60
80
100
120
140
160
180
200
TIME ~ SECONDS

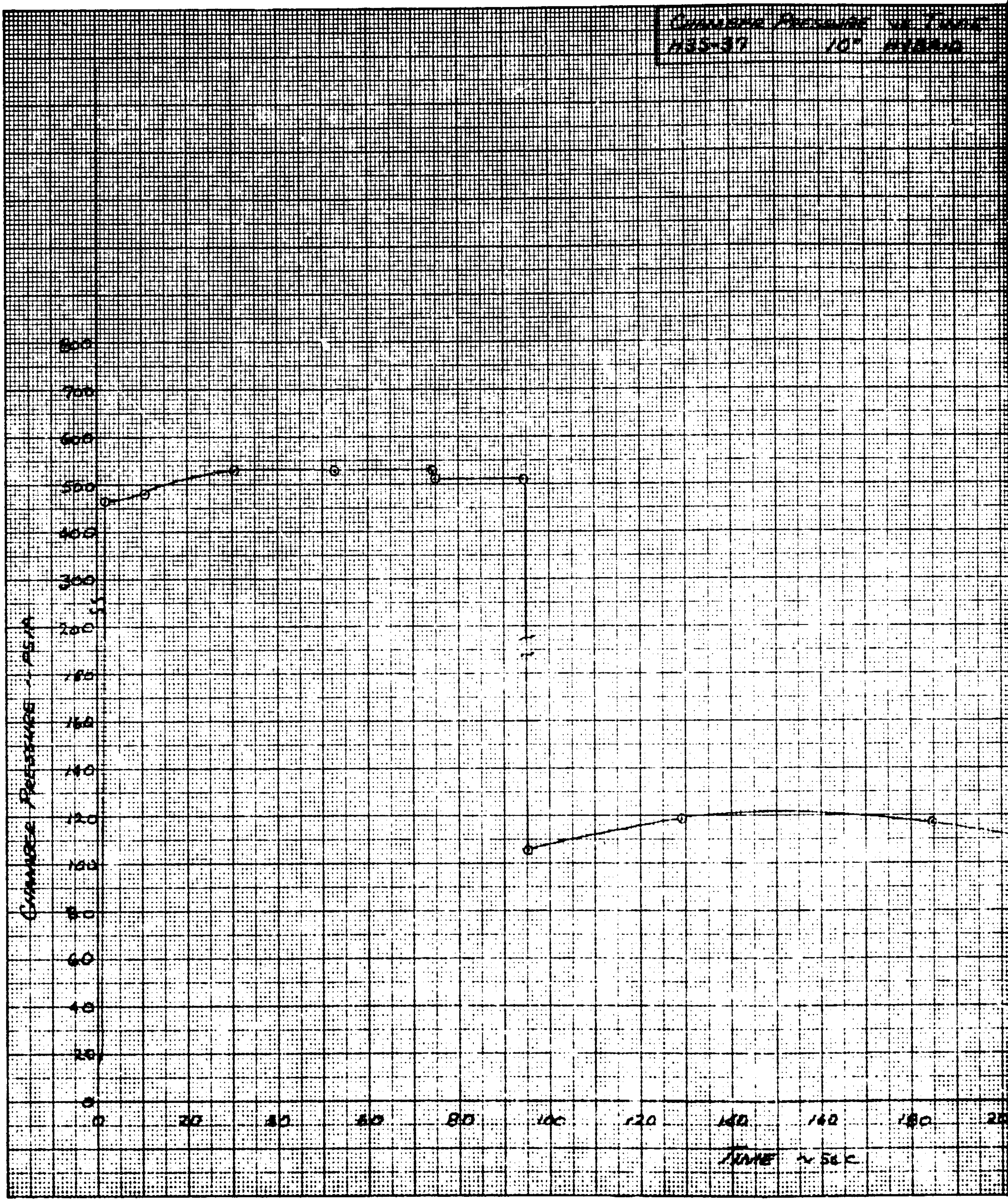

VS. TIME
140 160 180 200 220 240 260 280
TIME — SECONDS


CHAMBER PRESSURE VS TIME
10" HYBRID
CHAMBER PRESSURE ~ PSIA
800
700
600
500
400
300
200
0
0
20
40
60
80
100
120
140
TIME ~ SEC.

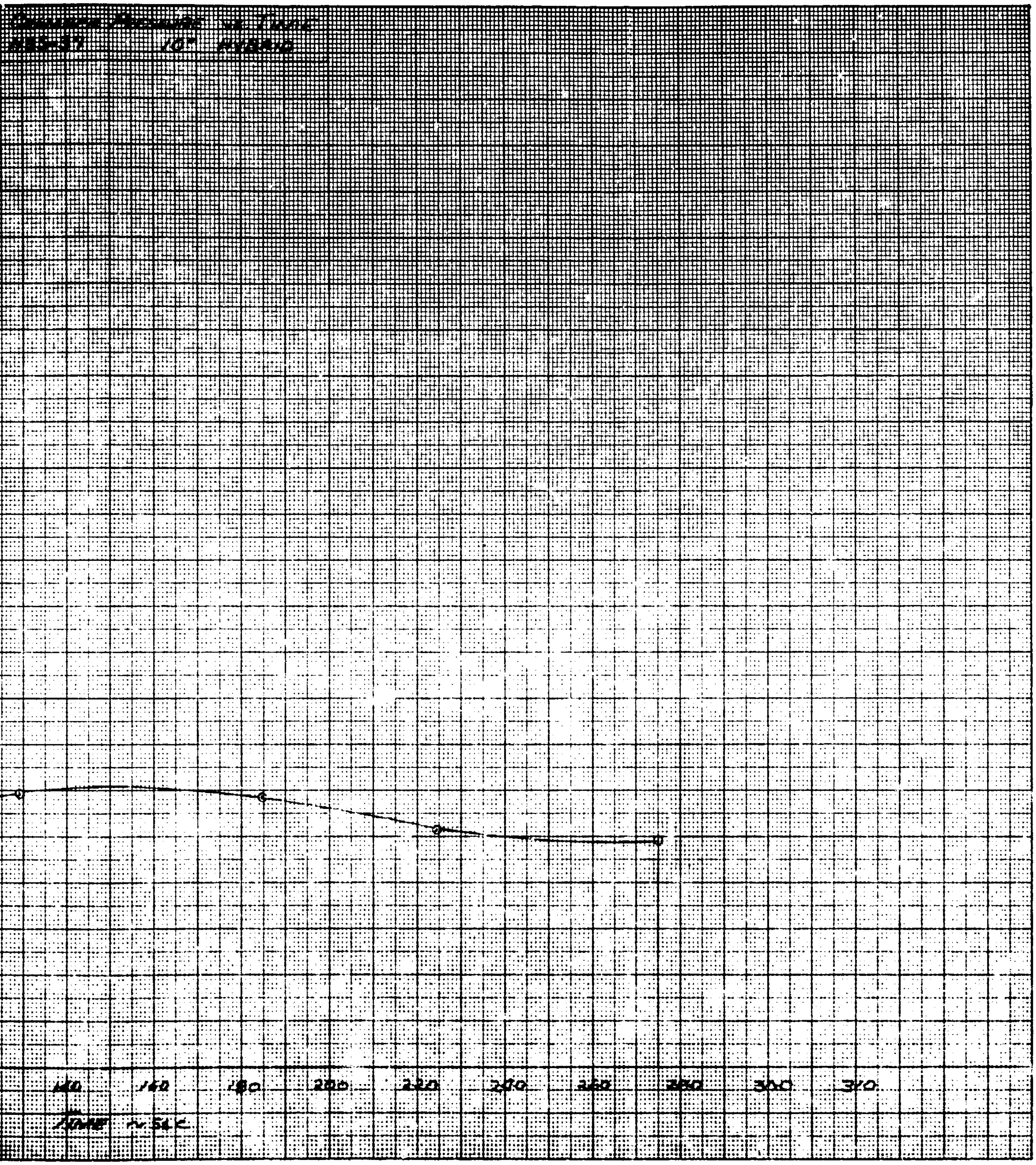

THRUST VS TIME
THRUST ~ LBS.
0
20
40
80
100
120
TIME ~ SEC.



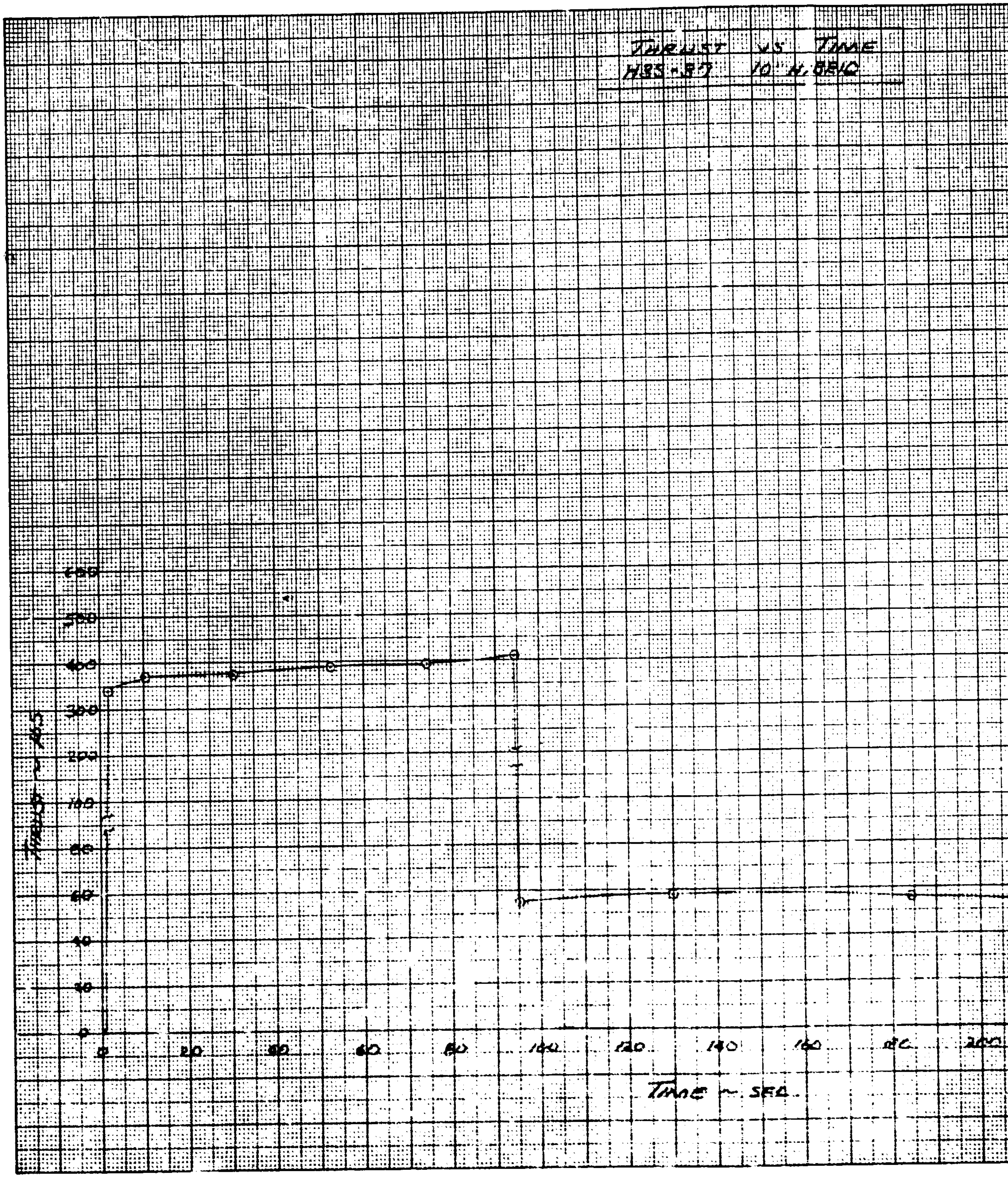
ẆOXIDIZER VS TIME
HBS-35 10" HYBRID
ẆOX ~ LB/SEC
1.8
1.6
1.4
1.2
1.0
.8
.6
.4
.2
0
0
20
40
60
80
100
120
140
TIME ~ SEC.



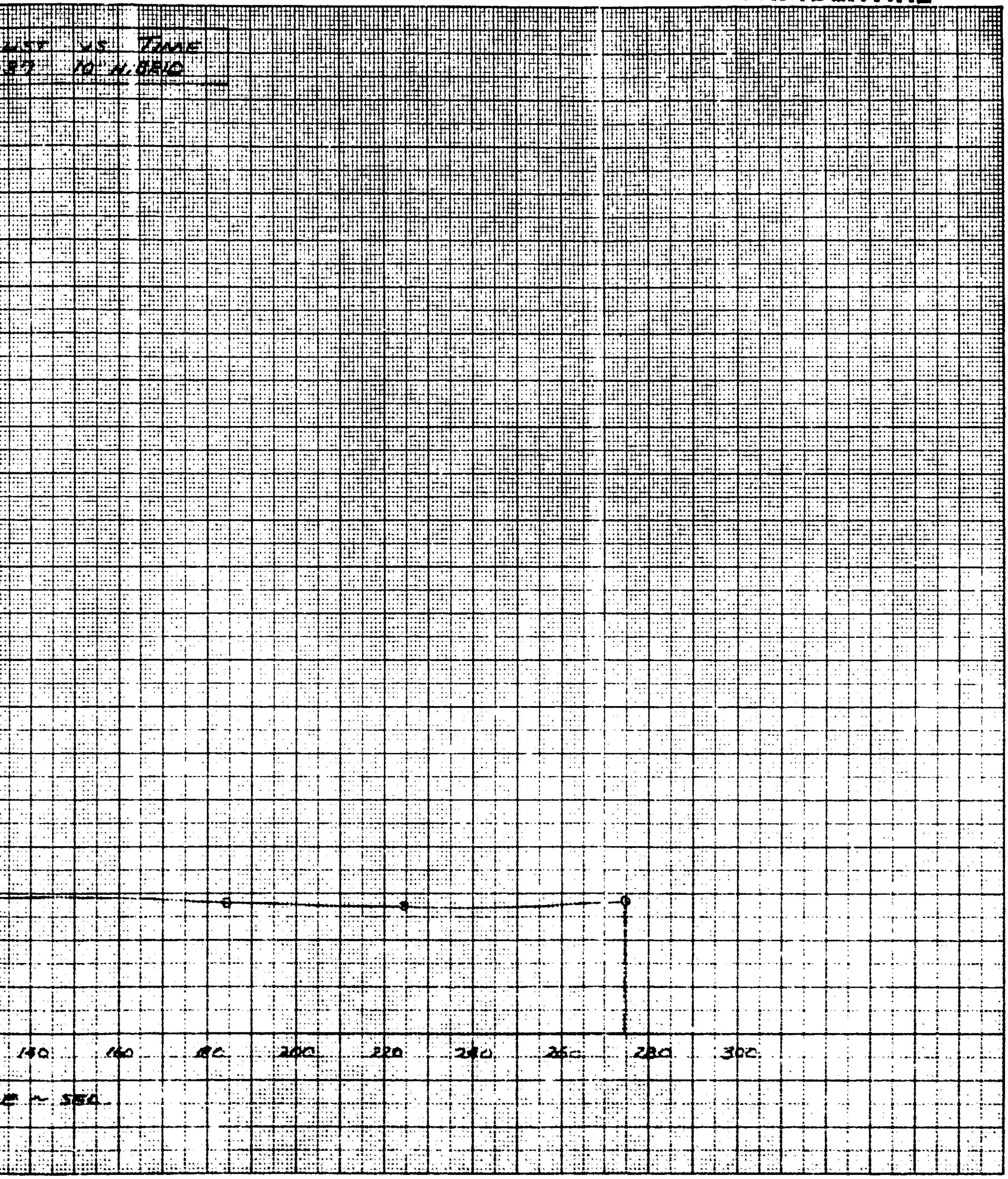
CHAMBER PRESSURE vs TIME
H35-37
10" HYBRID
CHAMBER PRESSURE ~ PSIA
TIME ~ SEC
0
20
40
60
80
100
120
140
160
180
200
300
400
500
600
700
800

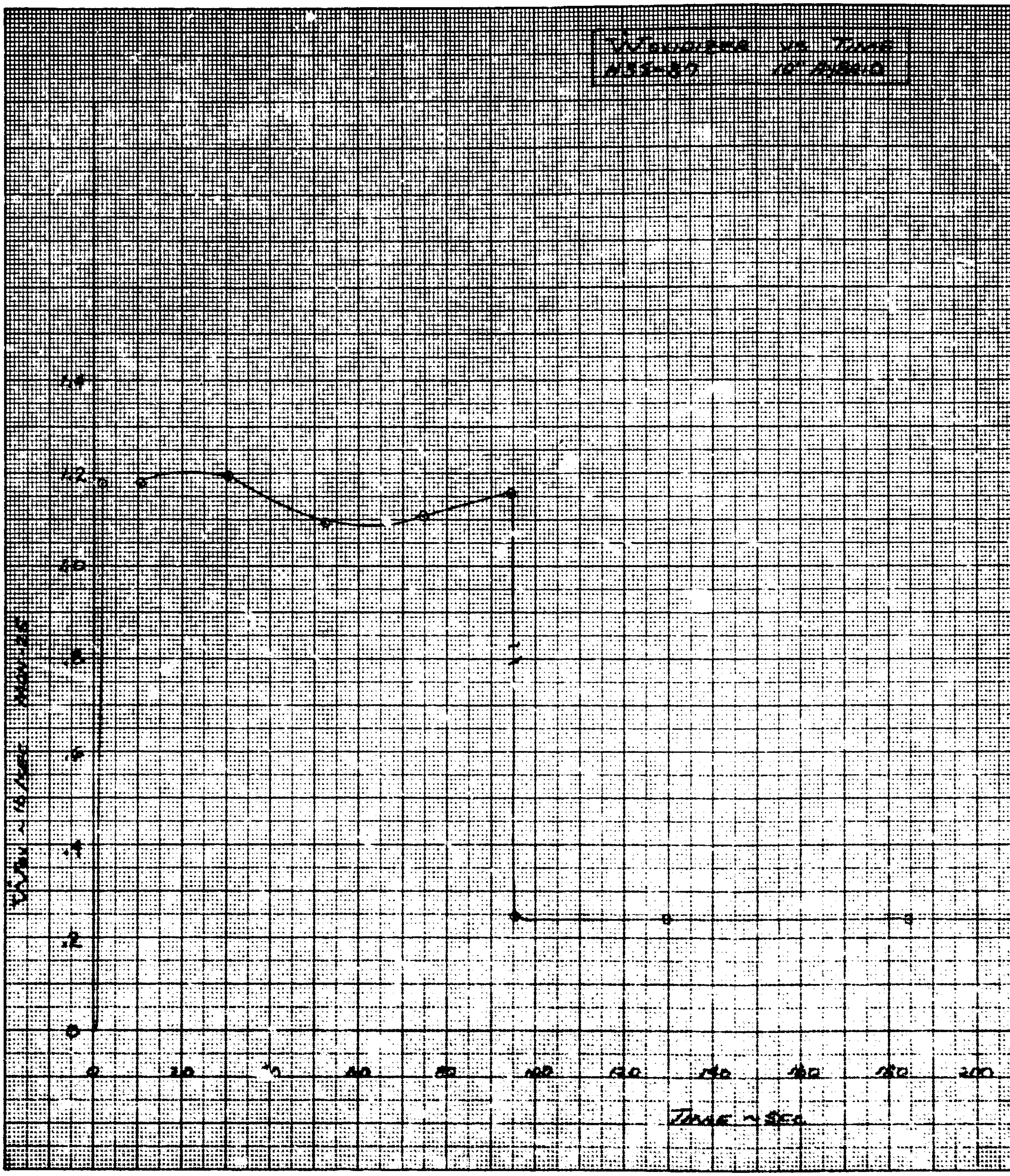


10" HYBRID
160
180
200
220
240
260
280
300
TIME ~ SEC

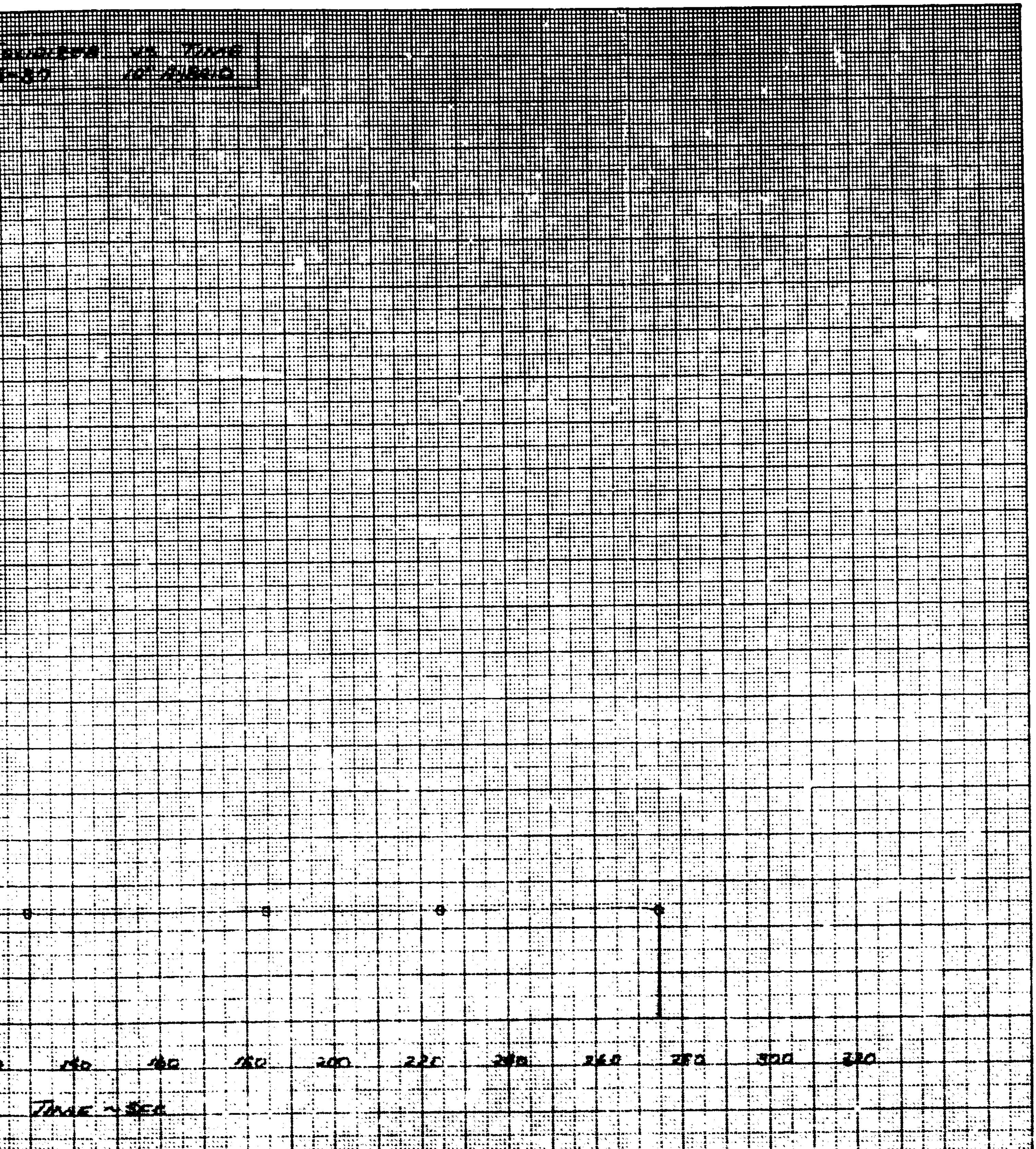

THRUST VS TIME
THRUST ~ LBS
TIME ~ SEC.
0
20
40
60
80
100
120
140
160
200

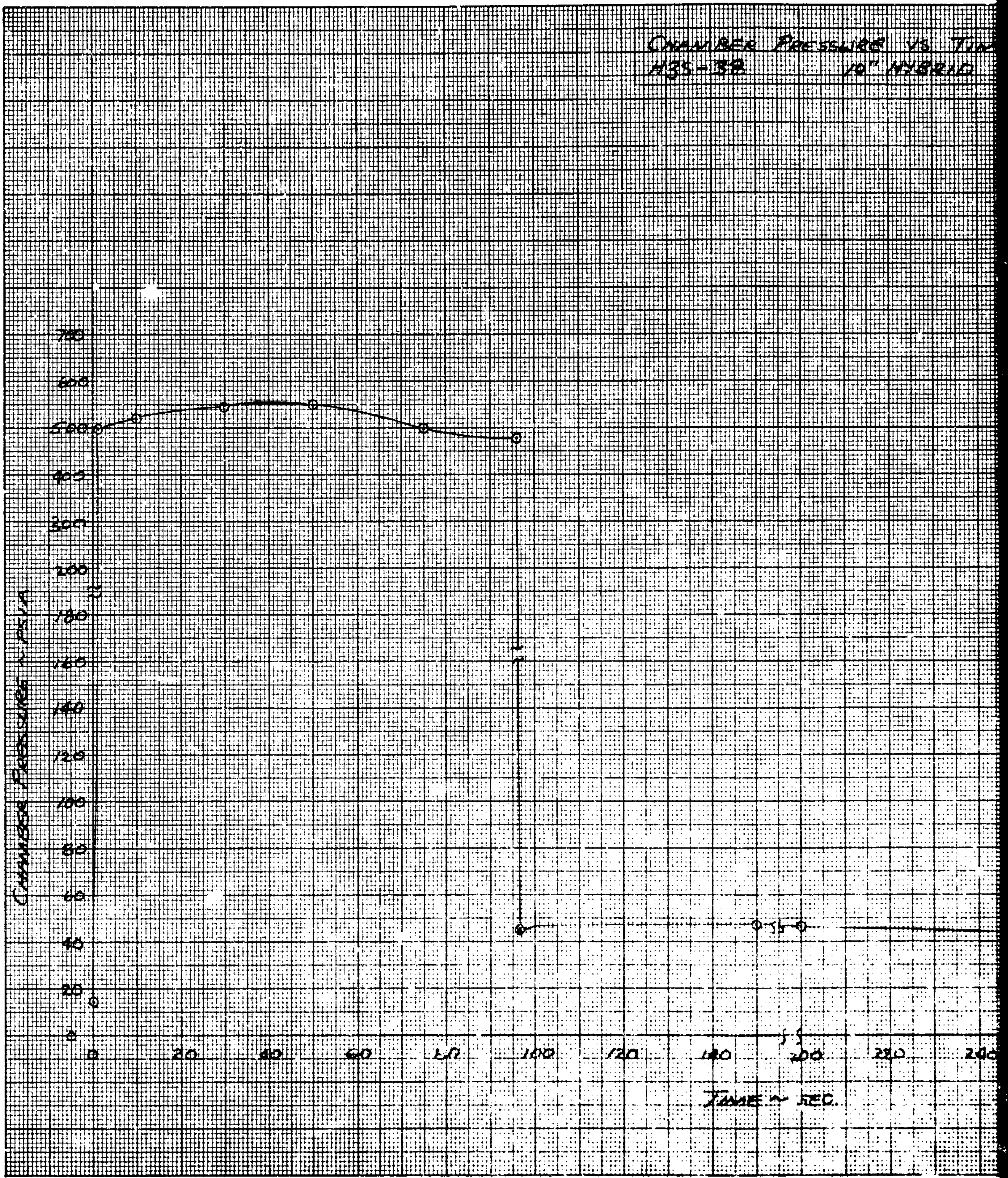
CONFIDENTIAL



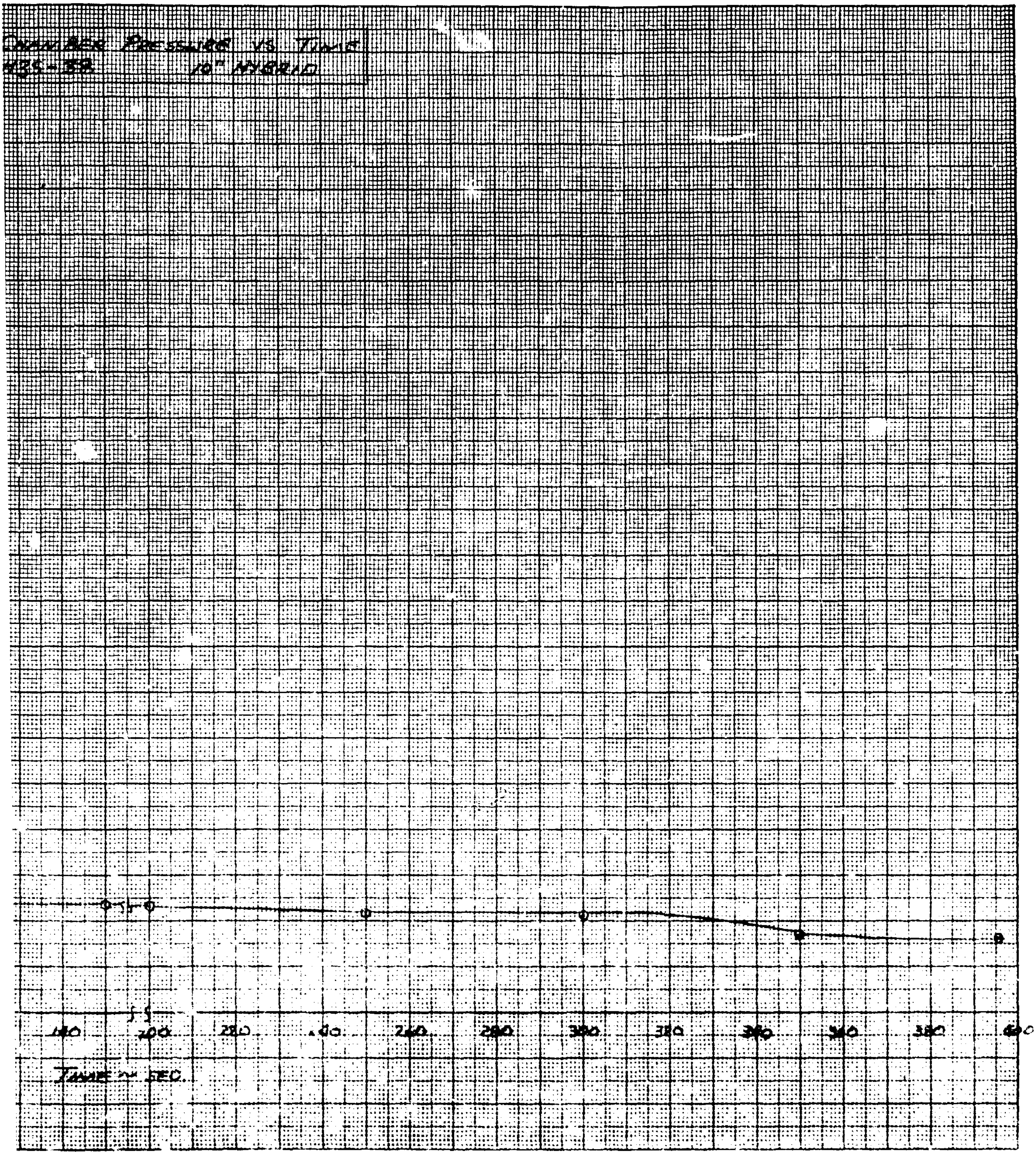


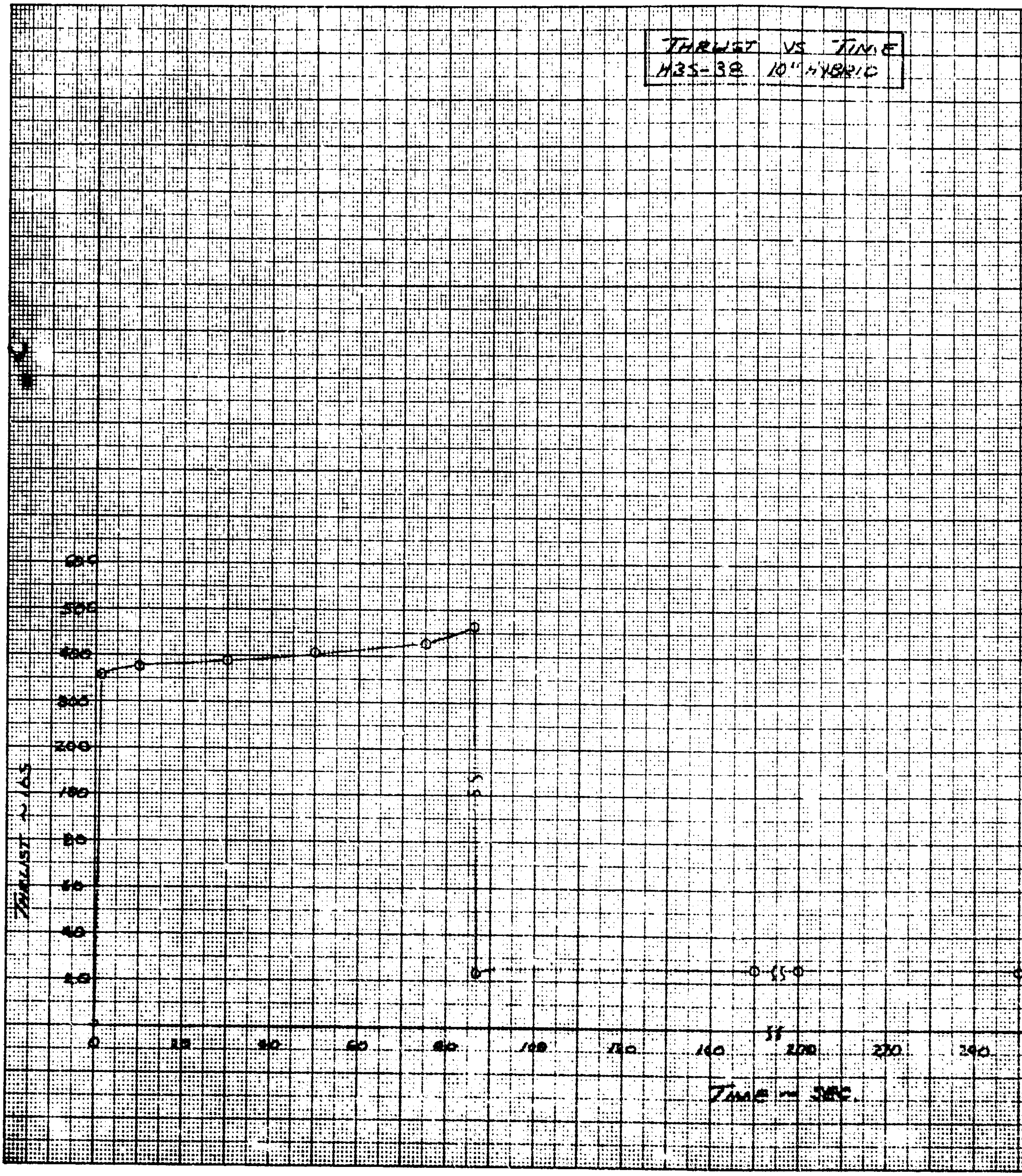
Wsolidifying vs Time
H35-87 10" Airfoil
1.4
1.2
1.0
.8
.6
.4
.2
0
0
20
40
60
80
100
120
140
160
180
200
Time ~ Sec


140
160
180
200
220
240
260
280
300
320
Time ~ Sec

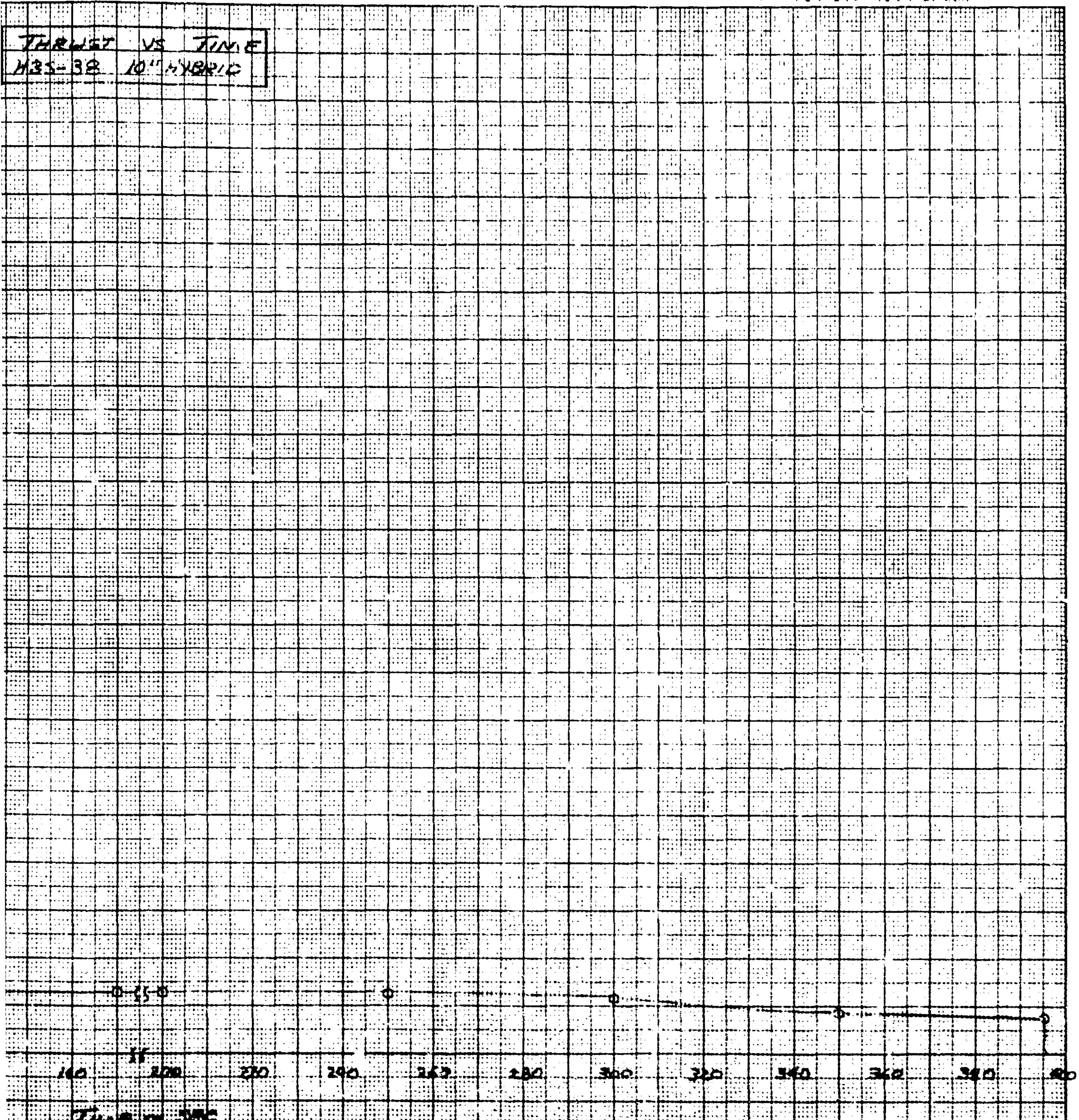


CHAMBER PRESSURE VS TIM
H3S-38
10" HYBRID
CHAMBER PRESSURE ~ PSIA
700
600
500
400
300
200
180
160
140
120
100
80
60
40
20
0
0
20
40
60
80
100
120
140
200
220
240
TIME ~ SEC.

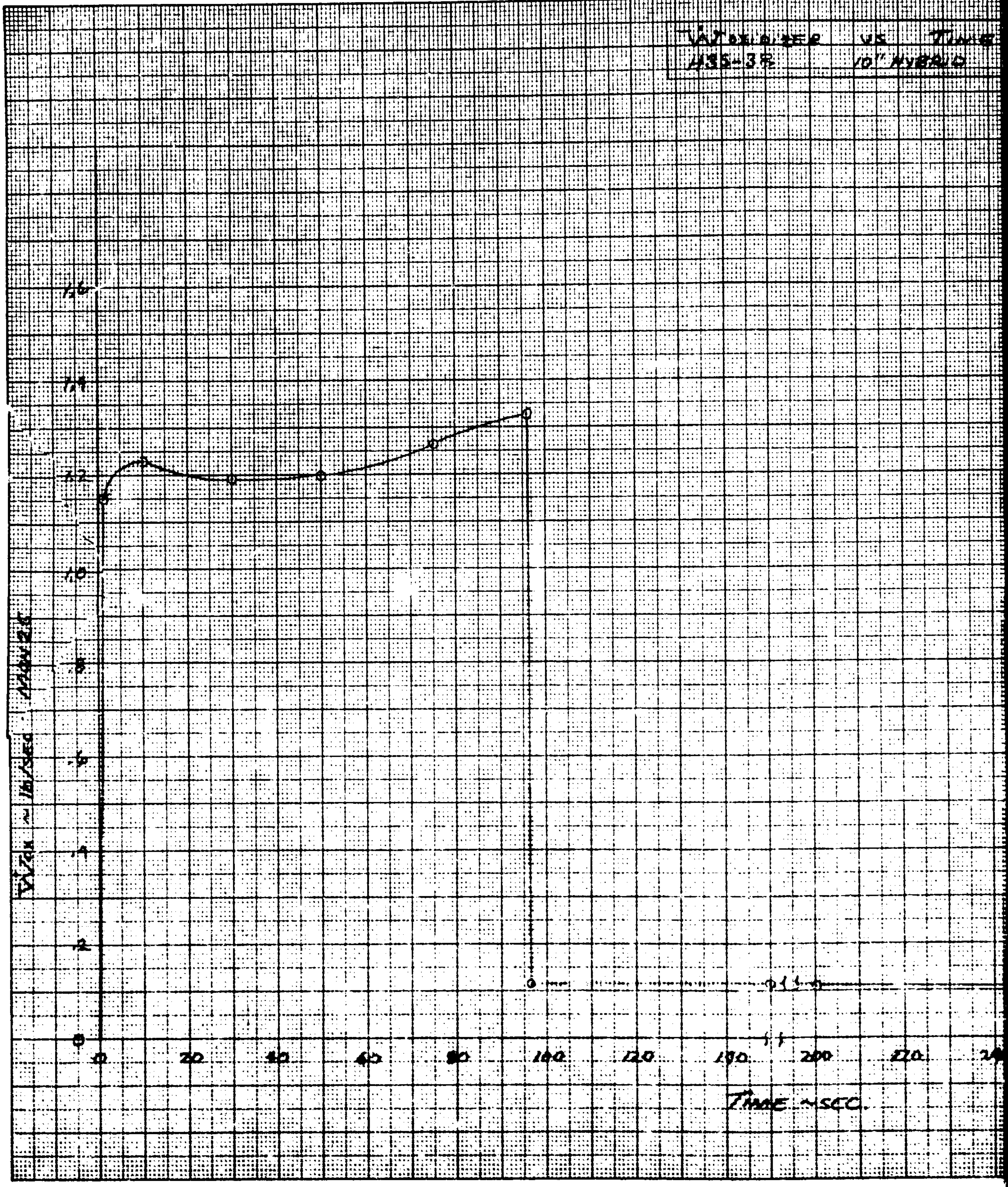

CHAMBER PRESSURE VS TIME
10" HYBRID
TIME ~ SEC

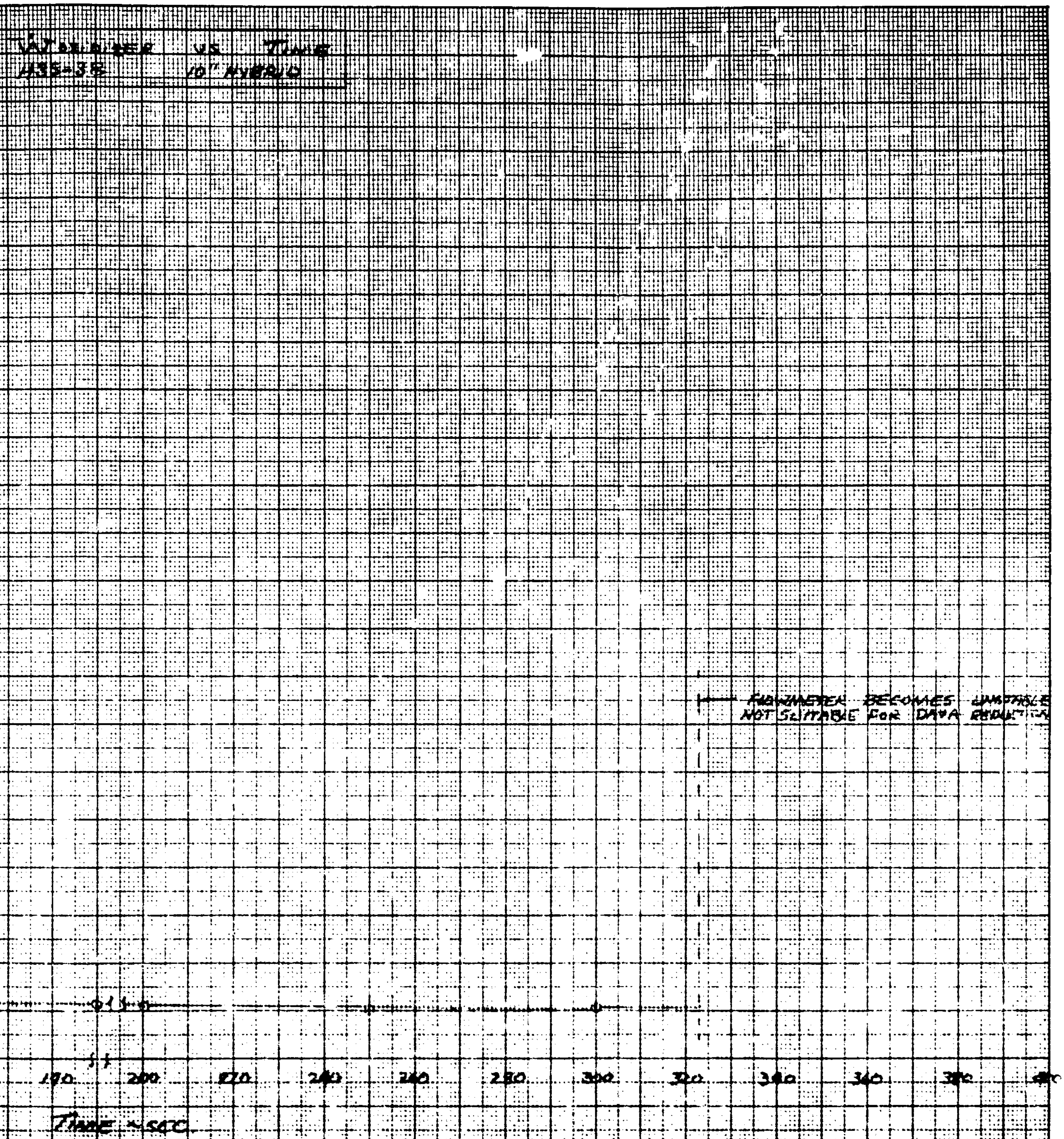


THRUST VS TIME
H35-38 10" HYBRID
THRUST ~ LBS
TIME ~ SEC.

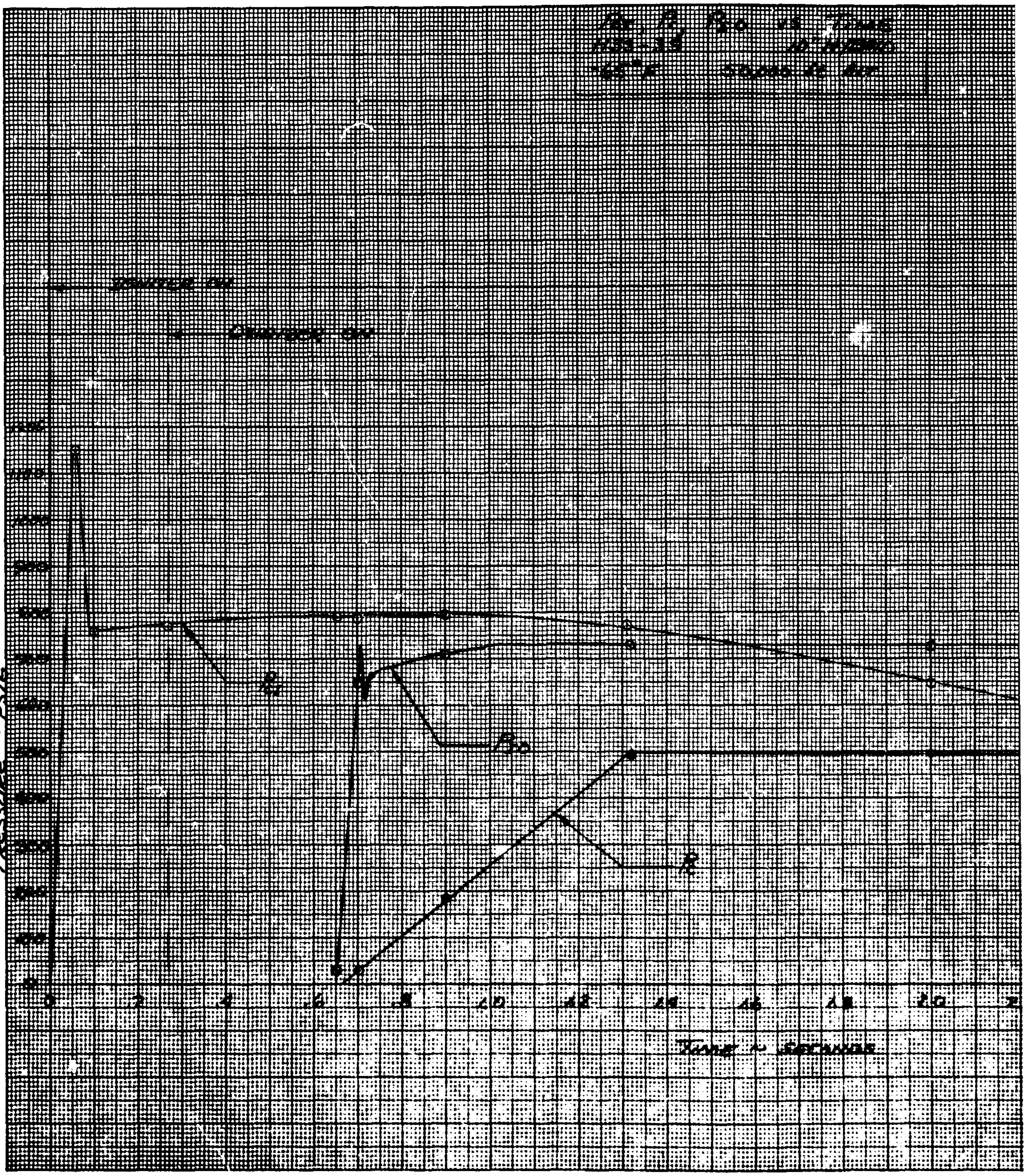


CONFIDENTIAL

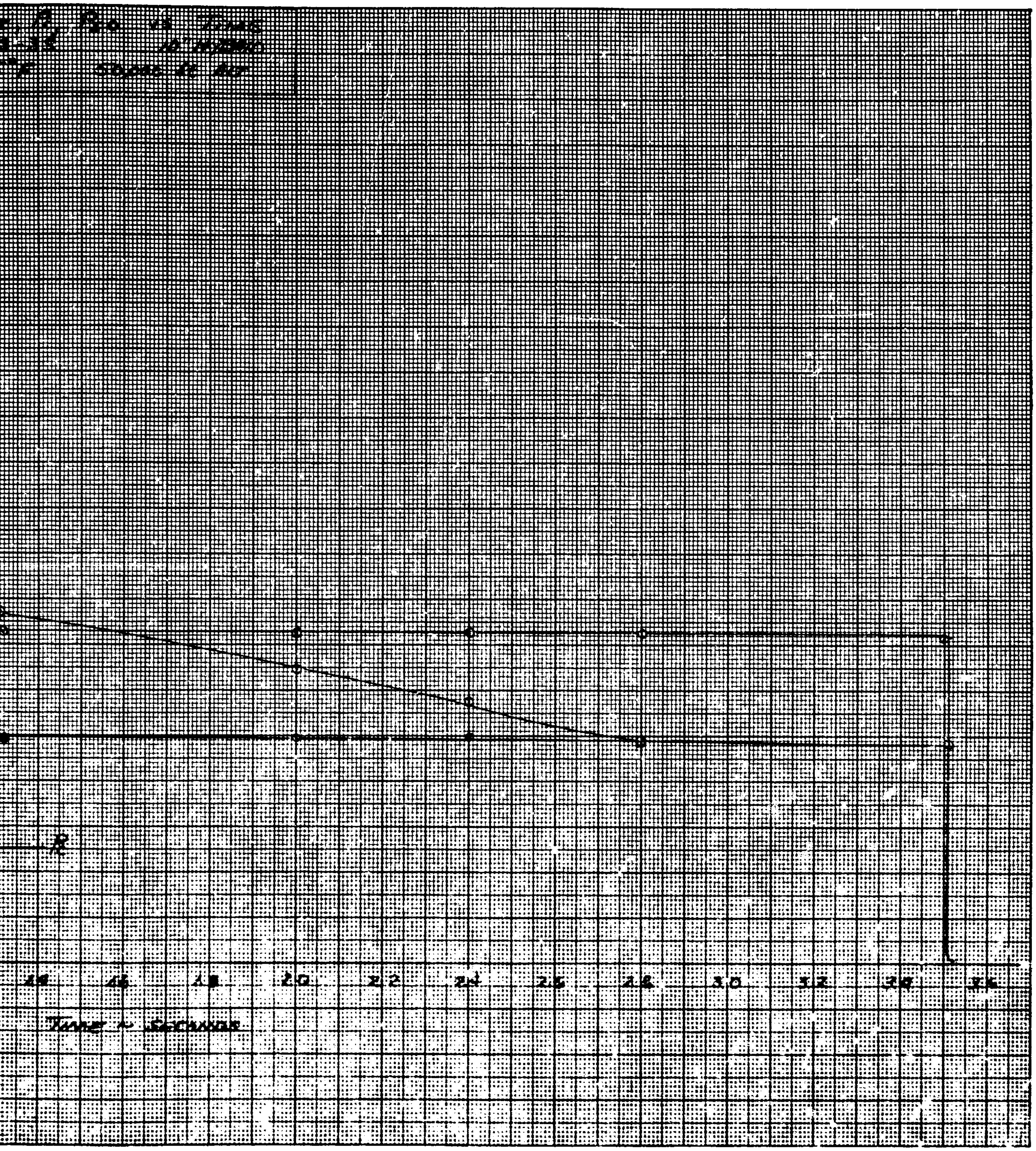

VS
10" HYBRID
1.6
1.4
1.2
1.0
.8
.6
.4
.2
0
20
40
60
80
100
120
200
220
TIME ~SEC.


VS TIME
10" HYBRID
FLOWMETER BECOMES
NOT SUITABLE FOR DATA
190
200
220
240
260
280
300
320
340
360
TIME ~ SEC

2



IGNITER ON
PRESSURE ~ PSIG
0
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
2.0
TIME ~ SECONDS


2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.4
3.6
Time ~ Seconds

APPENDIX III

DESCRIPTION OF COMPUTER PROGRAM AND FREE-FIELD NUMBERS (LF14ZAZ Hybrid Motor Performance Analyzer)

SECTION I

COMPUTER PROGRAM DESCRIPTION

1. IDENTIFICATION

Program Title:	Hybrid Motor Performance Analyzer
Library Number:	LF14ZAZ
Computer:	B 5500
System:	Data Com Version 1 Patches 1-82
Compiler:	Data Com Burroughs Extended ALGOL (60) Version 1 Patches 1-5
Programmer/Analyst:	Ken Guy, Ext. 2030
Customer:	R. A. Jones
Date:	25 December 1966

2. PURPOSE

A. To calculate the overall efficiency (N_C^*) of a motor test, such that the computed weight (output) of propellant expended is equal to the measured weight (input) of propellant provided.

B. Having satisfied the equality of 2A, to calculate and print 15 time-varying parameters characterizing the motor firing.

3. INPUT

All input data are on cards. Multiple cases are allowed, with sequence specifications as required by the INPUT routine (see section II of this appendix).

Card

C1. (<restricted Hollerith card>):* Any string of characters needed to form a title card

C2. (<restricted ffcard>): The following values as <ffnumber>s:

A. Start Time of Test (sec)

* Refer to section II of this appendix for free-field metalinguistics.

B. Time Step (sec) — Time step must evenly divide boost time.

Note: Time step $\leq \Delta T_{MAX}$, where ΔT_{MAX} is the time step such that for any time T, start time $\leq T \leq$ end time, $O/F(T) \leq O/F(T - \Delta T_{MAX}) \times 1.15$ and $O/F(T) \geq O/F(T - \Delta T_{MAX}) \times 0.85$, except near the boost-sustain interface.

C. End Time of Test (sec)

Note: In this paper, "boost time" refers to the time of the boost-sustain interface and is used solely in describing boost-plus-sustain tests. "End time" or "final time" refers to the time of final motor cutoff (i.e., time of test completion); if the test is a boost, the "final time" is the time of the boost cutoff, and is not referred to as "boost time."

D. Printing Time Step (sec)

The 15 parameters mentioned in 2B are, assuming the equality of 2A, output at every time T such that:

1. T = start-time
2. Start-time<T<final-time and T MOD printing-time-step = 0
3. T = end-time.

E. Maximum number of motor tests to achieve the equality of 2A

F. Motor radius (in.)

G. Motor length (in.)

H. Fuel port radius at start time (in.)

I. Fuel density ($lb/in.^3$)

J. Expended weight of propellant (lb)

K. Acceleration due to gravity (ft/sec^2)

L. Error bound for equality in 2A (recommended: 0.05)

M. Nozzle thrust coefficient efficiency.

C3. (<restricted ffcard>): $\dot{W}_{ox}$ FGEN* (lb/sec; sec)

C4. (<restricted ffcard>): Exist area FGEN (in.^{2}; sec)

C5. (<restricted ffcard>): Pressure FGEN (lb/in.^{2}; sec)

C6. (<restricted ffcard>): Gamma FGEN (; sec)

C7. (<restricted ffcard>): Chamber-pressure drop FGEN(; sec)

C8. (<restricted ffcard>): Ambient pressure FGEN(lb/in.^{2}; sec)

C9. One of the following:

A. (<restricted ffcard>): Thrust FGEN (lb; sec)

B. (<restricted Hollerith card>): Boost time (sec)

C. (<restricted Hollerith card>): Blank card.

C9-A is used if the thrust curve is known either to boost or to end time (i.e., if the test is a boost and the thrust curve is known, or if the test is a boost plus sustain and the thrust curve is known only for the boost). In the latter case, the program will compute the rest of the FGEN. The first card of the <ffcard> set must contain at least two <ffnumber>s.

C9-B is used if the test is a boost-plus-sustain and the thrust FGEN is unknown.

C9-C is used if the test is only a boost, and the thrust FGEN is unknown.

C10. One of the following:

A. (<restricted ffcard>): Throat area FGEN (lb; sec)

B. (<restricted Hollerith card>): Throat area at start time, throat area at end of time (in.^{2})

C. (<restricted Hollerith card>): Throat area at start time, throat area at boost time, throat area at end time (in.^{2}), boost time (sec).

* FGEN refers to the set of values needed to characterize a piecewise linear approximation to a curve. The first value is the integer <ffnumber> (=K) of points (abscissa–ordinate pairs) describing the piecewise linear line. The remaining values are the <ffnumber>s: Abscissa_1, Ordinate_1, Abscissa_2, Ordinate_2, . . . , Abscissa_k, Ordinate_k. The entire set contains 2k+1 values. In our case, all FGEN are time functions. Abscissas must be increasing.

C10-A is used whenever the throat area is completely known. The first card of the <ffcard> set must contain at least four <ffnumber>s.

C10-B is used if the test is a boost and the throat area FGEN is unknown. Both values are <ffnumber>s, and they both are confined to the same card.

C10-C is used if the test is a boost plus sustain and the throat area FGEN is unknown. All four values are <ffnumber>s, and all four are confined to the same card. If the test is a boost-plus-sustain, and if an FGEN curve exhibits step function characteristics at this interface, the following procedure should be used to represent the step:

1. For a boost time T_B, let the value of the FGEN curve (F) from the left be $F(T_B)^-$, and from the right be the value $F(T_B)^+$. Choose some small value ϵ ($\leq 10^{-3}$), and assign a new point $F(T_B+\epsilon) = F(T_B)^+$, while retaining the old point $F(T_B)^-$. Thus, the step is now a slope with base $= \epsilon$.

2. Every FGEN curve with step-function characteristics at boost time must be described as in 1, with the same ϵ. This latter requirement is very important.

C11. C_{th}^* FMAP data. All of the following:

11A	(<restricted ffcard>):	Integer number (=K) of oxyfuel-ratio (=O/F_i) values, $O/F_1, O/F_2, \dots, O/F_K$
11B	(<restricted ffcard>):	Integer number (=N) of level pressure curve (=PC_i) values, $PC_1, PC_2, \dots, PC_N$
11C	(<restricted ffcard>):	$C_{th}^*(1,1), C_{th}^*(1,2), \dots, C_{th}^*(1,N), C_{th}^*(2,1), C_{th}^*(2,2), \dots, C_{th}^*(2,N), \dots, \dots, C_{th}^*(K,1), C_{th}^*(K,2), \dots, C_{th}^*(K,N)$.

All values of the Card-11 group are <ffnumber>s.

4. OUTPUT

The following describes output for normal operations and may be altered by diagnostics output. The output information under discussion starts on the page indicated, but may be continued on as many pages as needed to complete the output.

A. Page 1

Listing of data deck, with current date.

B. Page 2

The title (see Card 1), the current date, and an edited representation of Cards 3, 4, 5, 6, 7, 8, 9A (if used) and 10A (if used).

C. Page 3 (Under Confidential Status)

An edited representation of Card 11 and Cards 2, 9B (if used), and either 10B or 10C (if either is used).

D. Page 4 (Under Confidential Status)

1. A columnar tabulation from start-time to end-time of the following 16 time-varying parameters:

   a. Time

   b. $\dot{W}_{OX}$ (input)

   c. Expansion ratio ϵ (calculated)

   d. Thrust (input, completed, or wholly calculated)

   e. Chamber pressure (input)

   f. Throat area (input or calculated)

   g. Thrust coefficient $C_F \cdot N_{CF}$ (calculated)

   h. I_{sp} (calculated)

   i. C^*DEL (calculated)

   j. $\dot{W}_F$ (calculated)

   k. Radius (calculated)

   l. W_O (calculated)

   m. Oxyfuel-ratio (calculated)

n. $\dot{R}$ (calculated)

o. G_o (calculated)

p. Weight propellant expended (calculated).

2. The N_C^* yielding the equality of 2A (such a yield is hereafter termed a "successful test").

3. The error function involved in computing the throat area (if the throat area was not input).

   This error-function, F(time), is linear and passes through the point (start time, initial error function {output value}) and the point (end or boost time {whichever is less}, final error function {output value}). The ordinate of each point is, respectively,

$$\left.\frac{\text{THRUST}}{PC \cdot C_F \cdot AT}\right|_{\text{start-time}}, \quad \left.\frac{\text{THRUST}}{PC \cdot C_F \cdot AT}\right|_{\text{end time}}$$

   Zero error is the line: error-function = 1.

5. RESTRICTIONS

A. Restrictions Imposed on Value

1. The values of Card 2 have the following bounds, in the form (lower bound, higher bound):

a.	(0. 0, 0. 0)	f.	(0. 0, 60.)	j.	(0. 0, 2 at 5)
b.	(0. 05, 5.)	g.	(0. 0, 400)	k.	(0. 0, at 02)
c.	(0. 0, at 03)	h.	(0. 0, 60.)	l.	(0. 01, 1.)
d.	(0. 1, 10.)	i.	(0. 0, 0. 1)	m.	(0. 89, 1.)
e.	(15. , at 02)				

2. The number of input points in an FGEN curve must be >1, <102. If the thrust FGEN is to be completed to final time in a boost-plus-sustain, it is recommended that the number of input points for the thrust FGEN be <71.

3. The value of ϵ must not change (see note with Card 10C).

4. The following values have the bounds:
   a. Boost time: $(0, 10^3)$
   b. Initial throat area: $(0, 10^3)$
   c. Final throat area: $(0, 10^3)$
   d. Boost throat area: $(0, 10^3)$.

B. Restrictions Imposed on Options

1. Either Card 9A and any card of Card 10, or Card 10A and any card of Card 9, must be used. Card 9A with thrust only to boost time for a boost-plus-sustain test may not be used with Card 10A.

2. The input boost time must be different from the input final (end) time.

C. Miscellaneous Restrictions

1. Restrictions imposed by the INPUT routine (see section II of this appendix).

2. The input FMAP C^*_{th} must be composed of not more than 50 pressure curves, with each curve containing not more than 50 oxyfuel-ratio points.

The restrictions A-1, A-2, A-4, B-1, B-2, and C-1 are program monitored and, when violated, produce an error message. A-1, A-2, A-4, B-1, and B-2 cause the current motor test to be flushed.

6. DIAGNOSTICS

A. Diagnostics as provided by INPUT routine (see section II of this appendix).

B. Diagnostics as provided by restrictions A-1, A-2, A-4, B-1, and B-2.

C. If the thrust coefficient is unobtainable after 20 iterations, a message is printed.

D. If the input data does not produce a Max N_C^* and Min N_C^* enclosing that N_C^* yielding the equality of 2A, the current motor test is flushed outputting:

1. The restricting N_C^* bound
2. The main function $F(O/F, \text{time}, N_C^*)$ which, for all time T, start-time$\leq T \leq$end-time, must have a zero for some O/F, $\{$Min O/F of Card 11A$\} < O/F < \{$Max O/F of Card 11A$\}$.
3. The final results of a firing at this N_C^*.

7. GENERAL INFORMATION

A. Average time for one test ~60 sec

B. Storage requirements ~13,000 words.

SECTION II

DESCRIPTION OF FREE-FIELD NUMBERS

1. DEFINITION AND SYNTAX OF FREE-FIELD NUMBER

A. Definition

<ffnumber>	::=	<unsigned number> <comma>/ <unsigned number> <ffstring> <comma>/+ <unsigned number> <comma>/+ <unsigned number> <ffstring> <comma>/- <unsigned number> <comma>/- <unsigned number> <ffstring> <comma>
<unsigned number>	::=	<decimal number>/<exponent part>/ <decimal number> <exponent part>
<decimal number>	::=	<unsigned integer>/<decimal fraction>/<unsigned integer> <decimal fraction>
<exponent part>	::=	@ <integer>
<decimal fraction>	::=	·<unsigned integer>
<integer>	::=	<unsigned integer>/+<unsigned integer>/-<unsigned integer>
<comma>	::=	,
<unsigned integer>	::=	<ffdigit>/<unsigned integer> <ffdigit>
<ffstring>	::=	<ffletter>/<ffstring> <ffletter>/ <ffstring> <ffdigit>

<ffdigit> ::= 0/1/2/3/4/5/6/7/8/9/<blank space>

<ffletter> ::= A/B/C/D/E/F/G/H/I/J/K/L/M/N/
O/P/Q/R/S/T/U/V/W/X/Y/Z/+/-/x/
=/≠/≥/≤/>/</(/)/[/]/*/←/&/./;/:/
<blank space>

<blank space> ::= {a single unit of horizontal spacing which is blank; an unpunched or skipped column on a card}

B. Syntax

1. A <ffnumber> must always end in a <comma>, and must contain only one <comma>. The <ffstring> must never start with a <ffdigit>, but must start with a <ffletter>; thereafter, up to the <comma>, any combination or "string" of <ffletter>s or <ffdigit>s is allowed. The <comma>, the @, and the / are not a part of the <ffletter> definition.

2. Examples of <ffnumber>s:

   a. The value of each <ffnumber> is 123. 456

      123. 456,

      123. 4   5 6,

      1 2 3 . 45 6,

      123. 456 = THE % FOR NO. 1 (I. E. 2#),

      1. 23 4 56 @ +0 2,

      +1. 23456@+2,

      1. 23456@2,

      123. 456@0,

      123456@-3,

      123. 456   ,

b. The value of each <ffnumber> is 2.0

2.0,

2,

002,

2@0,

2.0 00 0,

2. ,

2 OUNCES OF #4 THREAD(*),

c. The value of each <ffnumber> is 7 (integer)

7.0,

7,

7.4,

7.4999,

.7@1,

7 POINTS FOR F(x) = "TIME",

07POUNDS ,

Note: If the value of an ff<number> is intended to be integer, the value taken will be largest integer [<ffnumber> + 0.50000...] ; hence 7.4999 is 7.

d. The value of each <ffnumber> is 4.0×10^{23}

4@23,

40@22,

+4 0 00. 00 @ 2 0 ISHA RDTOREA D ,

3. Examples of confusing <ffnumber>s:

The values of each line is not (i) 70492 or (ii) only 70492.

70,492	[value of 70; and Incomplete Value — see below]
70492	[Incomplete Value]
X = 70492,	[Ignored Value — see below]

7049I,	[value of 7049; "I" is mispunched "2"]
70492 SETS(I.E., 2 GROUPS)	[Value of 70492; and Incomplete Value]

4. Punching <ffnumber>s on an <ffcard>; Incomplete Values; and Ignored Values

   a. Definition of <ffcard>

<ffcard>	::=	<restricted ffcard>/ <unrestricted ffcard>
<unrestricted ffcard>	::=	<unrestricted Hollerith card>/<unrestricted ffcard> <unrestricted Hollerith card>
<restricted ffcard>	::=	<restricted Hollerith card>/<restricted ffcard> <restricted Hollerith card>
<unrestricted Hollerith card>	::=	{ordinary 80 column "IBM" card with full 80 columns available}
<restricted Hollerith card>	::=	{ordinary 80 column "IBM" card with full 71 columns available (Cols. 1–71) and a "/" punched in Col. 72; Cols. 73–80 are reserved for sequencing}

   b. Syntax

The <ffcard> is a set of Hollerith cards. The <ffcard> set contains either <unrestricted Hollerith card>s or <restricted Hollerith card>s, but not both. The only characteristic not indicated in the definition (to do so would unduly complicate matters) is, if the next card is not an <ffcard>, then the last <restricted Hollerith card> or <unrestricted Hollerith card> of the current

<ffcard> set must contain at least one <comma> needed to end a used <ffnumber>, (i.e., an <ffnumber> required as input by the program).

The <ffcard> definition includes the <restricted ffcard> refinement because many programs employ one of the several card-input routines (e.g., INPUT) which require certain card and case sequencing in Columns 73 – 80. For such programs, refer to the appropriate input-routine writeup.

In the following example, the letters LC indicate the last Hollerith card, the letters UR indicate "unrestricted," the letter R indicates "restricted," and the left bracket ({) indicates an <ffcard>.

Example of the value 123.456 and the value 74 as punched on an <ffcard>:

```
            COL                                    COL        COL
            1                                      72          80

{UR,LC:     123.456,   74,

{UR,LC:        123.456 PØUNDS,               74 FEET,

{R,LC:      123.456,   74,                        /

{R,LC:         123.456 PØUNDS,         74 FEET,   /

{UR:          1     2
 UR:             3     .
 UR:                 4            5                    6
 UR:               PØU          N
 UR:             D     S,     7
 UR:
 UR,LC:            4                          FE  E T,

{R:           1     2                             /
 R:              3     .                          /
 R:                  4                     5     6/
 R:                PØU          N                 /
 R:              D     S,     7                   /
 R:                                               /
 R,LC:             4                   FE     ET, /

{UR:
 UR,LC:       23456@-    3PØUNDS,   7.          4@+      1FEET,
```

c. Incomplete Values

An incomplete value is encountered whenever the intended <ffnumber> does not have its ending <comma>; the result is the continual reading of the Hollerith card(s) until a <comma> is encountered or an END OF FILE situation occurs. In either case, the program receives data both incorrect and out of sequence.

Example: The values 74, 123.456, 27 are intended to be represented as <ffnumber>s on an <ffcard>; but 123.456 is actually an incomplete value

```
        COL                                          COL     COL
        1                                            72       80

UR:     74,        123.456
UR:
UR,LC:        27,
```

The second <ffnumber> has the value 123.45627, and the further reading of any <ffnumber>s would be out of sequence by one <ffnumber>.

d. Ignored Values

An ignored value is encountered whenever the intended <ffnumber> begins with an <ffstring> instead of an <ffdigit>. The result is that the variable into which the <ffnumber> was to be stored is unchanged; the reading process ignores this <ffnumber> and proceeds to the next <ffnumber>. The proper sequence of <ffnumber>s is, however, unaltered.

Example: The values 72 and 123.456 are to be read; but the value 74 is ignored and the value 123.456 is properly read.

```
        COL                                          COL     COL
        1                                            72       80
UR,LC:  N = 74, 123.456 = M,
```

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(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) United Technology Center Dividion of United Aircraft Corporation Sunnyvale, California	2a. REPORT SECURITY CLASSIFICATION CONFIDENTIAL 2b. GROUP 4

3. REPORT TITLE

Hybrid Propulsion System for an Advanced Rocket-Powered Target Missile (U)

4. DESCRIPTIVE NOTES (Type of report and inclusive dates) Quarterly Technical Report covering period from 1 October 1966 through 31 December 1966

5. AUTHOR(S) (Last name, first name, initial)

Jones, Richard A.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
February 1967	259	None

8a. CONTRACT OR GRANT NO. AF 04(611) - 11632 b. PROJECT NO. c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) UTC 2220-QTR2 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) AFRPL-TR-67-54

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11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Air Force Rocket Propulsion Laboratory Research and Technology Division Air Force Systems Command United States Air Force

13. ABSTRACT

The development of a hybrid propulsion system for an advanced rocket-powered target missile has advanced through the seventh program month. During the past 3 months, the heavyweight motor test series was completed successfully, and designs have been finalized for the flightweight thrust chamber assembly components. The results of the final nozzle evaluation tests have shown that the nozzle configuration selected has a nozzle material erosion rate of 0.45 mils/sec. Motor ignition has been demonstrated at -65° F at sea-level conditions and at a simulated altitude of 50,000 ft. The required thrust ratings have been demonstrated at boost and sustain thrust levels for the durations specified, and step thrust operation has been verified over an 8 to 1 range. The flightweight feed system component buildup has been initiated and cold-flow checkout tests will be conducted during the next reporting period. The current status of the program indicates that the hybrid propulsion units to be used in the flight demonstration program will be delivered in accordance with the original schedule.

14. KEY WORDS	LINK A		LINK B		LINK C	
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